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MARTIAN POLAR CAP BOUNDARIES

FINAL REPORT, PART A

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G. E. Fischbacher
L. J. Martin
W. A. Baum

Planetary Research Center
Lowell Observatory
Flagstaff, Arizona 86001

ABSTRACT

The boundaries of the north and south polar caps of Mars were measured on more than 3,000 yellow and red photographs from the Lowell Observatory plate collection. These photographs, obtained between 1905 and 1965, included a good sampling of all Martian seasons. The boundaries of the caps were read at intervals of 10° in longitude on the Martian surface, and the data were averaged over time intervals equal to 1/36 of the Martian year. Readings were entered directly onto IBM cards by the "mark-sense" method, and computer programs were written to organize the results into the form of tabulations and plots.

Each of the polar caps is most favorably situated for measurement during the season when it is receding. After an initially erratic start, the melt phase of each cap was found to follow a well-defined curve that repeated itself very closely from one Martian year to another. During the melt phase, the mean deviations of measurements from various plates were only about 1°, and the variation from one Martian year to another was of similar magnitude.

INTRODUCTION

Although it has been known for more than 200 years that the polar caps of Mars change size seasonally, data concerning their boundaries have been rather limited and not particularly close in agreement. The data were reviewed in 1962 by E. C. Slipher in The Photographic Story of Mars (Sky Publishing Corporation, Cambridge, Massachusetts). Concurrent observations by different observers have sometimes disagreed by more than ten degrees in the width of the south polar cap, while data concerning the north polar cap have been almost non-existent.

Although the tilt of the Martian axis with respect to its orbital plane is about the same as that of the Earth, the seasonal change in the size of the caps is greater on Mars. Owing to the eccentricity of the Martian orbit, there is also a difference in behavior between the caps in the two hemispheres. Since the southern hemisphere of Mars has both the colder winter and the hotter summer, the seasonal variation of the south polar cap is greater than that of the northern cap.

Some observers have noted that the boundaries of the Martian polar caps are not always smooth circles. Various irregularities are seen, and a few of these have been found to recur each Martian year during the receding phase. Nevertheless, previous data on cap boundaries have sometimes been limited to angular widths of each cap as a whole.

The present study of the Martian polar caps differs from previous ones in several significant ways. Measurements were made on approximately ten times as many plates as had been utilized in any known previous study. Additionally, the measurements were made at individual meridians 10° apart in longitude as shown in Figure 1, so that a single plate would contribute as many as eleven points defining the boundary of each cap. This type of program was made possible by the design and construction of special image-reading equipment for this and related planetary studies. A vital role was also played by the utilization of an electronic computer capable of combining many thousands of readings into the desired tabulations and plots.

PLATE MATERIAL

Martian photographs used for this polar cap study were all drawn from the Lowell Observatory plate collection. These photographs were taken between 1905 and 1965 with five telescopes, including (a) the Lowell 24-inch refractor, (b) the Lowell 42-inch reflector, (c) the Lamont-Hussey 27-inch refractor in South Africa, (d) the National University Observatory telescope in Argentina, and (e) the 18-inch refractor of Amherst College in Chile.

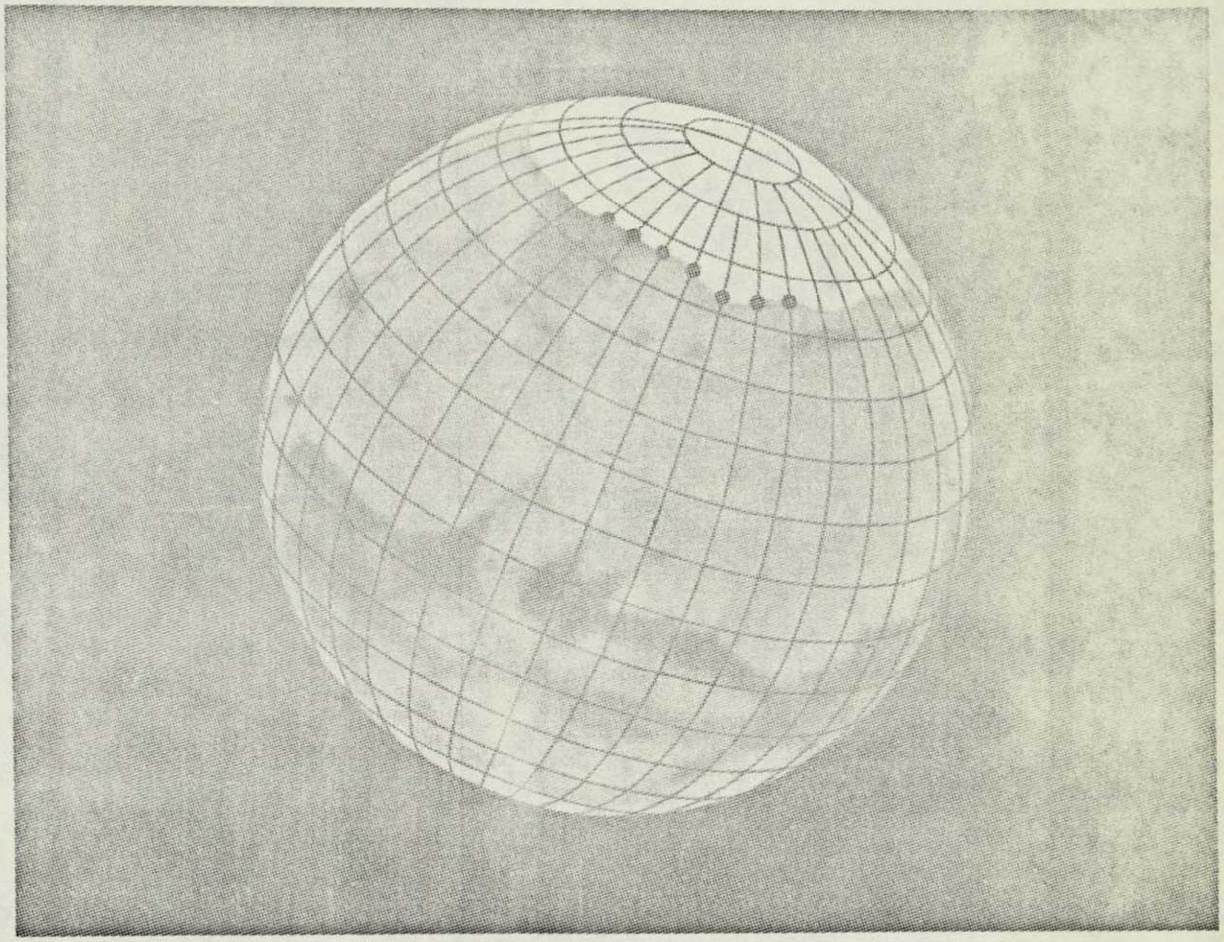


Figure 1. Schematic diagram showing how polar-cap boundary data were read from Mars photographs by superposition of a coordinate grid.

Attention was limited to plates photographed through green, yellow, orange, red, and infrared filters. All together, 3,196 such plates were examined, and polar-cap boundary data were read from most of them. Blue and ultraviolet photographs were excluded in order to avoid the effects of clouds and haze.

Because different telescopes and auxiliary lens systems were used, the Martian images ranged in size from about 1 mm to 8 mm in diameter. There were also substantial differences in photographic granularity and in the quality of the "seeing" at the time the photographs had been made.

Owing to the tilt of the Martian axis and the eccentricity of the Martian orbit, photographs in some seasons tend to be superior to others in providing accurate polar-cap boundary data. Each cap is better seen during its receding phase than during its growing phase, because each cap recedes (melts) during the season when it is tilted toward the Sun and therefore somewhat toward the Earth. Moreover, the eccentricity of the Martian orbit has the effect of giving us a closer view at times when the south pole is tilted toward us than when the north pole is.

Table I is a listing of all plate material from which polar-cap boundaries were actually measured. It shows the Martian seasonal coverage obtained surrounding the time of each opposition from 1905 through 1965. The Martian season is expressed in terms of the areocentric longitude of the Sun (ALS) in degrees after the Martian vernal equinox.

PROJECTION PLATE READER

After plates were initially examined on an ordinary light box, those of satisfactory quality were measured with the projection plate reader shown in Figure 2. This instrument was designed and built expressly for the present series of planetary image studies of which this polar-cap investigation has been a part. The general layout of the instrument and the optical specifications were developed at the Planetary Research Center, while detailed engineering and fabrication were carried out by the Richardson Camera Company in Phoenix. The projection plate reader has now been in use for more than two years at the Planetary Research Center.

The purpose of this instrument is to project individual planetary images onto a viewing screen where they can be superimposed upon a coordinate grid. Since the planetary images vary in size and orientation on the original plates, the instrument provides controls for precisely positioning, rotating, zooming, and focusing the projected images. The instrument also provided a separate optical system that enables a large area of plate encompassing many images to be viewed on the projection screen at low magnification so that

TABLE I.

Number of Plates from which Martian polar cap data were read, tabulated according to the year of the opposition and the Martian season (interval in areocentric longitude of the Sun).

Opposition	Areocentric Longitude of the Sun (Degrees)	Pole	Number of Plates
1905	135 - 144	N	7
		S	11
	145 - 154	N	3
		S	14
	155 - 164	S	22
	165 - 174	S	3
	175 - 184	N	4
1907	175 - 184	N	3
		S	21
	185 - 194	N	39
		S	89
	195 - 204	N	80
		S	103
	205 - 214	N	62
		S	88
	215 - 224	N	9
		S	15
	225 - 234	N	1
		S	19
	235 - 244	S	3
1909	245 - 254	S	4
	255 - 264	S	9
	265 - 274	S	6
	275 - 284	S	11
	285 - 294	S	10
	295 - 304	S	6
1911	295 - 304	S	1
	305 - 314	N	1
	315 - 324	N	6
	325 - 334	N	6
		S	1
	335 - 344	N	7
1914	015 - 024	N	1
1916	045 - 054	N	15
	065 - 074	N	2

Opposition	Areocentric Longitude of the Sun (Degrees)	Pole	Number of Plates
1918	085 - 094	N	6
1920	115 - 124	N	3
	125 - 134	N	6
		S	1
	135 - 144	N	9
		S	5
	145 - 154	S	3
1922	145 - 154	S	2
	155 - 164	S	9
	165 - 174	N	1
		S	10
	175 - 184	N	9
		S	14
	185 - 194	N	8
		S	15
	195 - 204	N	1
		S	3
	205 - 214	S	2
1924	185 - 194	S	3
	195 - 204	S	8
	205 - 214	S	3
	215 - 224	S	11
	225 - 234	S	30
	235 - 244	S	25
	245 - 254	S	19
	255 - 264	S	14
	265 - 274	S	14
	275 - 284	S	1
	285 - 294	S	3
1926	215 - 224	S	2
	225 - 234	S	1
	235 - 244	S	1
	245 - 254	S	3
	255 - 264	S	2
	265 - 274	S	4
	275 - 284	S	6
	285 - 294	N	10
		S	16
	295 - 304	N	13
		S	13
	305 - 314	N	19
		S	24

Opposition	Areocentric Longitude of the Sun (Degrees)	Pole	Number of Plates
1926	315 - 324	N	11
		S	7
	325 - 334	N	9
		S	9
1928	325 - 334	N	1
		S	1
	335 - 344	N	1
		S	1
	345 - 354	N	2
1929	005 - 014	N	4
1930	015 - 024	N	5
	025 - 034	N	11
		S	1
1931	035 - 044	N	10
	045 - 054	N	12
	055 - 064	N	1
1933	095 - 104	N	1
1935	095 - 104	N	3
	105 - 114	N	20
		S	1
	115 - 124	N	21
	125 - 134	N	4
		S	1
	135 - 144	N	2
1937	125 - 134	S	1
	135 - 144	N	3
		S	14
	145 - 154	N	9
		S	27
	155 - 164	N	2
		S	20
	165 - 174	S	5
1939	155 - 164	S	1
	165 - 174	S	2
	185 - 194	S	8
	195 - 204	N	12
		S	54
	205 - 214	N	37
		S	101

Opposition	Areocentric Longitude of the Sun (Degrees)	Pole	Number of Plates
1939	215 - 224	N	59
		S	140
	225 - 234	N	4
		S	55
	235 - 244	S	9
	245 - 254	S	15
	255 - 264	S	15
	265 - 274	S	10
1941	225 - 234	S	1
	235 - 244	S	9
	245 - 254	S	11
	255 - 264	S	21
	265 - 274	S	26
	275 - 284	S	15
	285 - 294	S	40
	295 - 304	N	1
		S	3
	305 - 314	N	1
		S	6
	315 - 324	S	3
1943	305 - 314	N	1
		S	1
	315 - 324	N	11
	325 - 334	N	24
	335 - 344	N	15
	355 - 004	N	2
1944	355 - 004	N	1
1946	015 - 024	N	6
	025 - 034	N	6
		S	3
	035 - 044	N	2
1948	035 - 044	N	5
	045 - 054	N	3
	065 - 074	N	5
	075 - 084	N	1
1950	065 - 074	N	4
	075 - 084	N	21
	085 - 094	N	10
	095 - 104	N	7
		S	2
	105 - 114	N	2
	115 - 124	N	1

Opposition	Areocentric Longitude of the Sun (Degrees)	Pole	Number of Plates
1952	115 - 124	N	6
		S	5
	125 - 134	N	12
	135 - 144	N	4
	145 - 154	N	4
		S	7
1954	155 - 164	N	1
		S	24
	165 - 174	N	6
		S	42
	175 - 184	N	4
		S	48
	185 - 194	N	5
		S	85
	195 - 204	N	7
		S	41
	205 - 214	N	10
		S	25
	215 - 224	N	6
		S	28
	225 - 234	N	3
		S	10
1956	195 - 204	S	7
	205 - 214	S	20
	215 - 224	S	31
	225 - 234	N	1
		S	54
	235 - 244	S	75
	245 - 254	S	82
	255 - 264	S	31
	265 - 274	S	77
	275 - 284	S	63
	285 - 294	S	14
	295 - 304	S	15
	305 - 314	S	6
1958	285 - 294	N	1
	295 - 304	N	5
		S	4
	305 - 314	N	24
		S	3
	315 - 324	N	19
		S	14
	325 - 334	N	9
	335 - 344	N	17

Opposition	Areocentric Longitude of the Sun (Degrees)	Pole	Number of Plates
1960	355 - 004	N	3
		S	1
	005 - 014	N	25
1961	015 - 024	N	9
1963	035 - 044	N	7
	045 - 054	N	25
	055 - 064	N	2
1965	055 - 064	N	3
	065 - 074	N	2
	075 - 084	N	19
	085 - 094	N	9

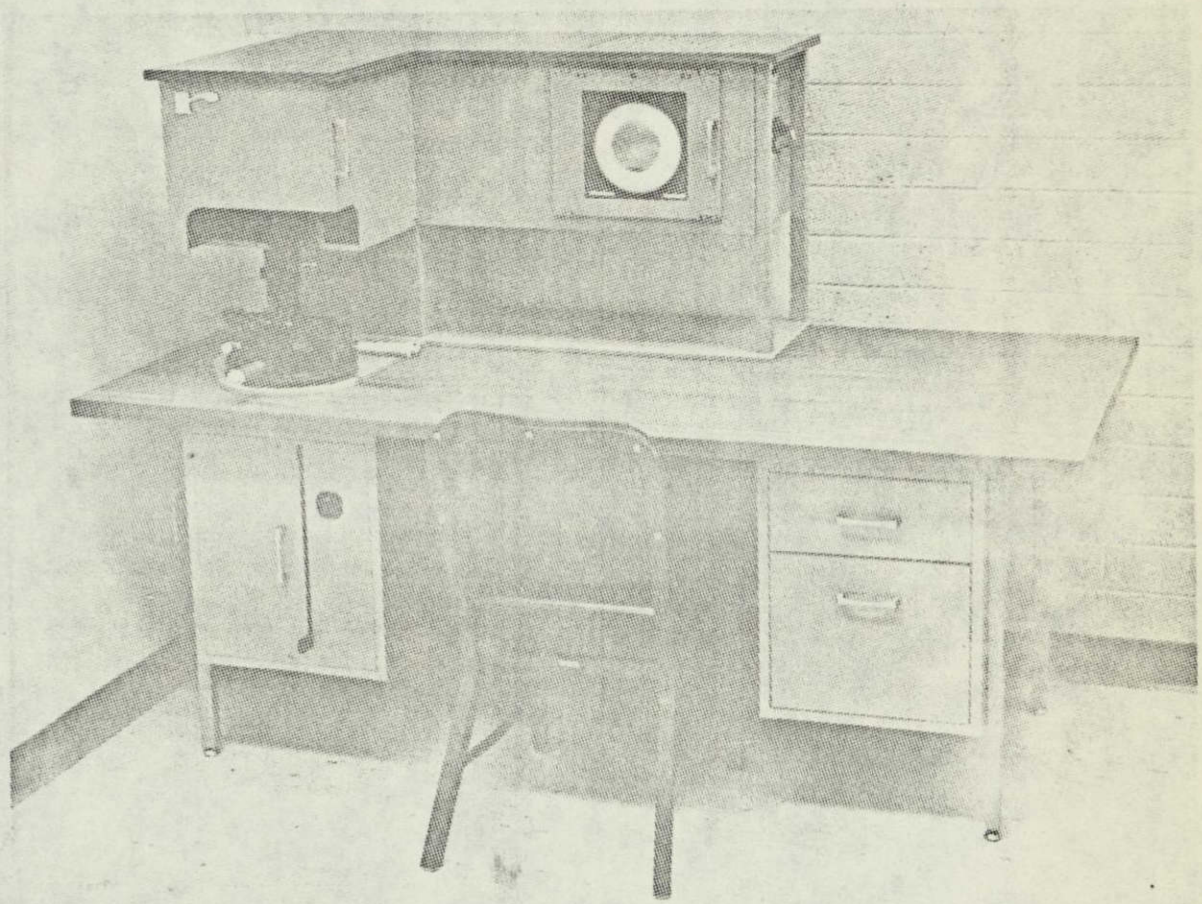


Figure 2. Projection plate reader.

individual images can be selected and centered for measurement. An operator seated in front of the instrument manipulates plates at his left, looks at projected images on the vertical screen in front of him, and has suitable reference material on the desk top beside him.

There are two separate lamp and condenser systems built into the pedestal at the left of the operator. One of these illuminates a 3-inch-diameter area of the plate and relays the lamp filament image to the position of a projection lens that displays the plate at a magnification of only 2.8 on the projection screen. The other lamp and condenser system provides a much more concentrated illumination of a 1/2-inch-diameter plate area and relays the lamp filament image to a variable distance that can be made to coincide with the effective nodal point of a zoom projection lens. This condenser system consists of two lens groups arranged so that the second group produces an image of the first at the plane of the photographic plate. As a result, images on the plate are illuminated with perfect uniformity for all settings of the zoom lens and the condenser system. The zoom lens provides magnifications ranging from 8.3 times up to 81 times, and a simple Vernier scale enables zoom settings to be duplicated or recorded.

The plate stage of the projection plate reader provided for three types of positional manipulation of the planet image. At the base of the stage is a rotational bearing with provision for centering the bearing on the optic axis of the zoom lens. Rotational settings can be read and reproduced to less than 0.1 degree. At the top of the stage is a simple parallel-motion linkage that permits coarse lateral positioning of the plate while maintaining a fixed angular orientation. Between the parallel-motion linkage and the rotational bearing are micrometer-driven orthogonal cross-slides for precise centering of the image. Plates are supported emulsion-side-up in special plate holders that define the location of the emulsion plane; thus, the focus is not sensitive to variations in plate thickness.

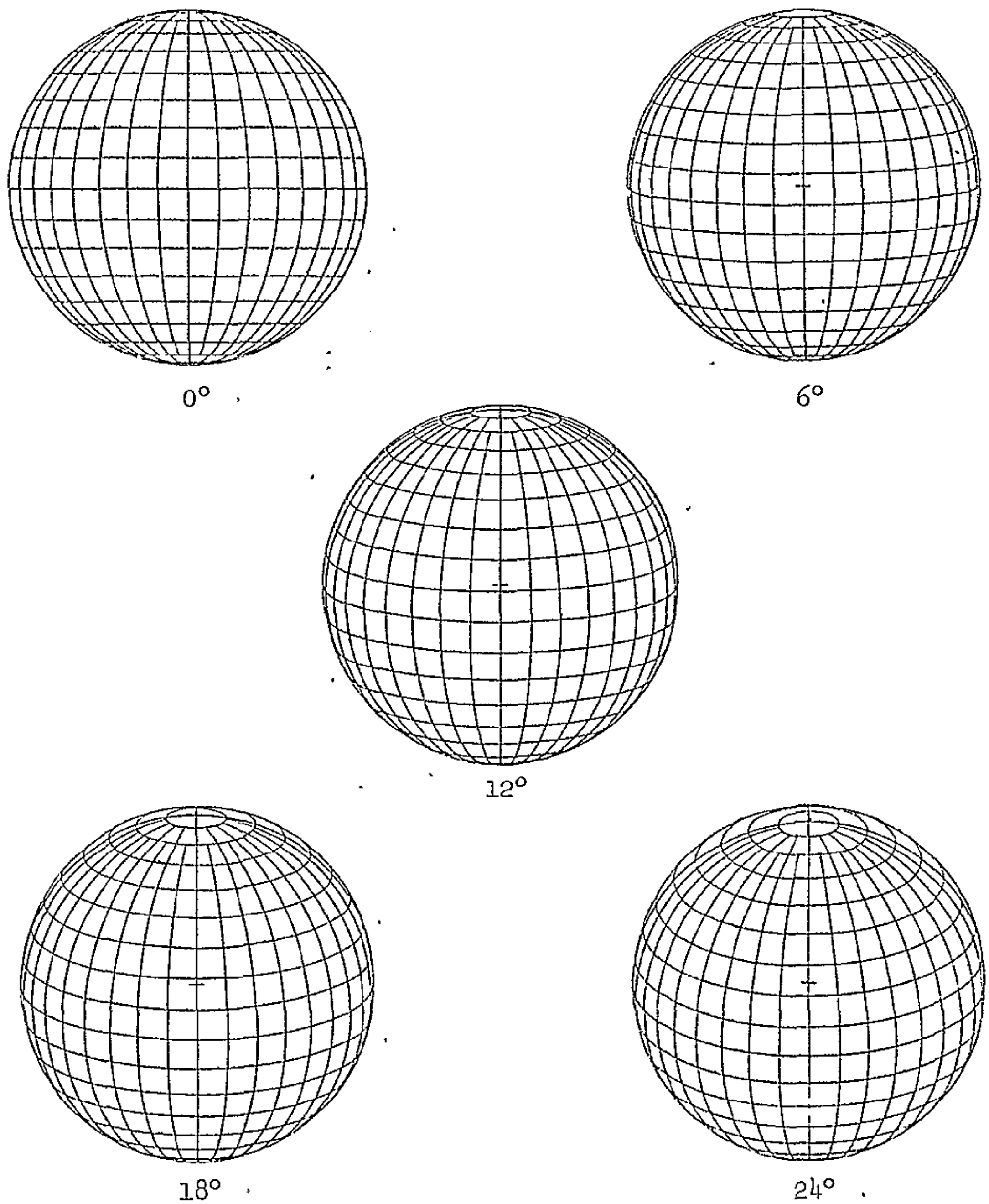
Images projected through the instrument are reflected by optically flat mirrors to a polacoat screen directly in front of a seated operator. About 160 different coordinate grids have been made at the Planetary Research Center for placing in contact with the projection screen. These grids were photographically produced on cronar-based film, and they are provided with accurately-positioned punched holes that fit registration pins adjacent to the projection screen on the instrument.

Coordinate reticles used for the polar-cap measurements were of the type shown in Figure 3. The meridian lines (at which the polar-cap boundaries were read) are spaced 10° apart, and the circles of latitude are also 10° apart. A complete set of these grids provides for all tilts of the Martian axis over a range from -24° to +24° in steps of 2°; consequently, latitudes defined by the grids are never more than 1° in error when superimposed on projected images of the

Figure 3.

SAMPLES OF COORDINATE GRIDS USED FOR POLAR CAP READINGS

Figures under the grids indicate the tilt of the axis with respect to a plane normal to the line of sight.



planet. Three such sets of grids were reproduced in three different sizes on cronar film, namely, two inches, three inches, and four inches in diameter. When images could be zoomed to a small enough size, the two-inch grids were generally preferred. From tests of the optical system, it was established that image distortion was negligible over the range of magnifications and grid sizes used.

PLATE READING PROCEDURE

Using a coordinate reticle having the correct axis tilt for the image to be measured, the operator first positioned, rotated, zoomed, and focused an image of Mars with respect to the grid. The rotational orientation of the image was best determined if there was a sidereally trailed image on the plate being measured. Otherwise, surface features and even the polar cap itself could sometimes be used to judge orientation. Measurements of the polar-cap boundary near the central meridian were, of course, relatively insensitive to plate orientation. When the orientation was poorly known or was dependent upon the cap itself, boundary readings were not taken at large distances from the central meridian.

Since the boundary of a cap could best be judged in the absence of an overlaid grid, the grid was momentarily folded back out of the way and the estimated boundary of the polar cap was outlined with a grease pencil on a plastic sheet covering the projection screen. The coordinate grid was then dropped back into place, and the outlined boundary of the polar cap was read against the grid.

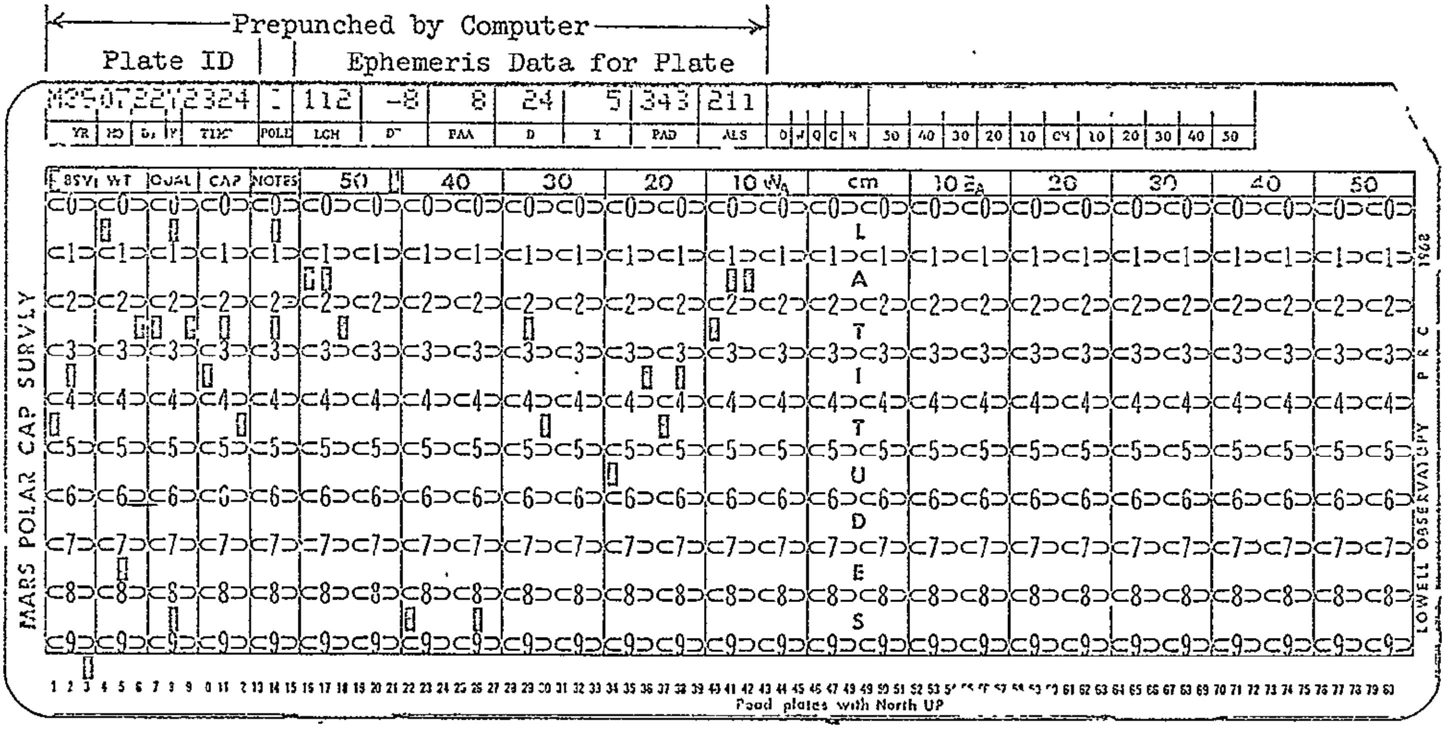
Data were taken directly onto IBM cards using the format reproduced in Figure 4. Each of the data cards had been prepunched by the computer with a plate identification and with some selected ephemeris data associated with that plate. The polar-cap boundary readings were then recorded by making marks with a soft pencil in the spaces shown on the card format in Figure 4. Each reading was a two-digit entry representing the latitude of the polar-cap boundary at the various meridians ranging from 50° west of the central meridian to 50° east of the central meridian. Ordinarily, readings were not taken over quite so broad a span of longitude. Columns at the left end of the card format identify the person making the readings, the relative weights attached to image quality and orientation accuracy, qualifying remarks concerning any peculiarities of the plate, notes concerning any unusual features of the cap, and general notes concerning things noticed in non-polar areas of the Martian images. The code for these entries is outlined in Table II.

Both the limb of the planet and the boundary of the cap are affected by the sharpness of the image and also by its density. Images of different sharpness and different density on the same plate provide some indication of the extent to which these factors affected zoom

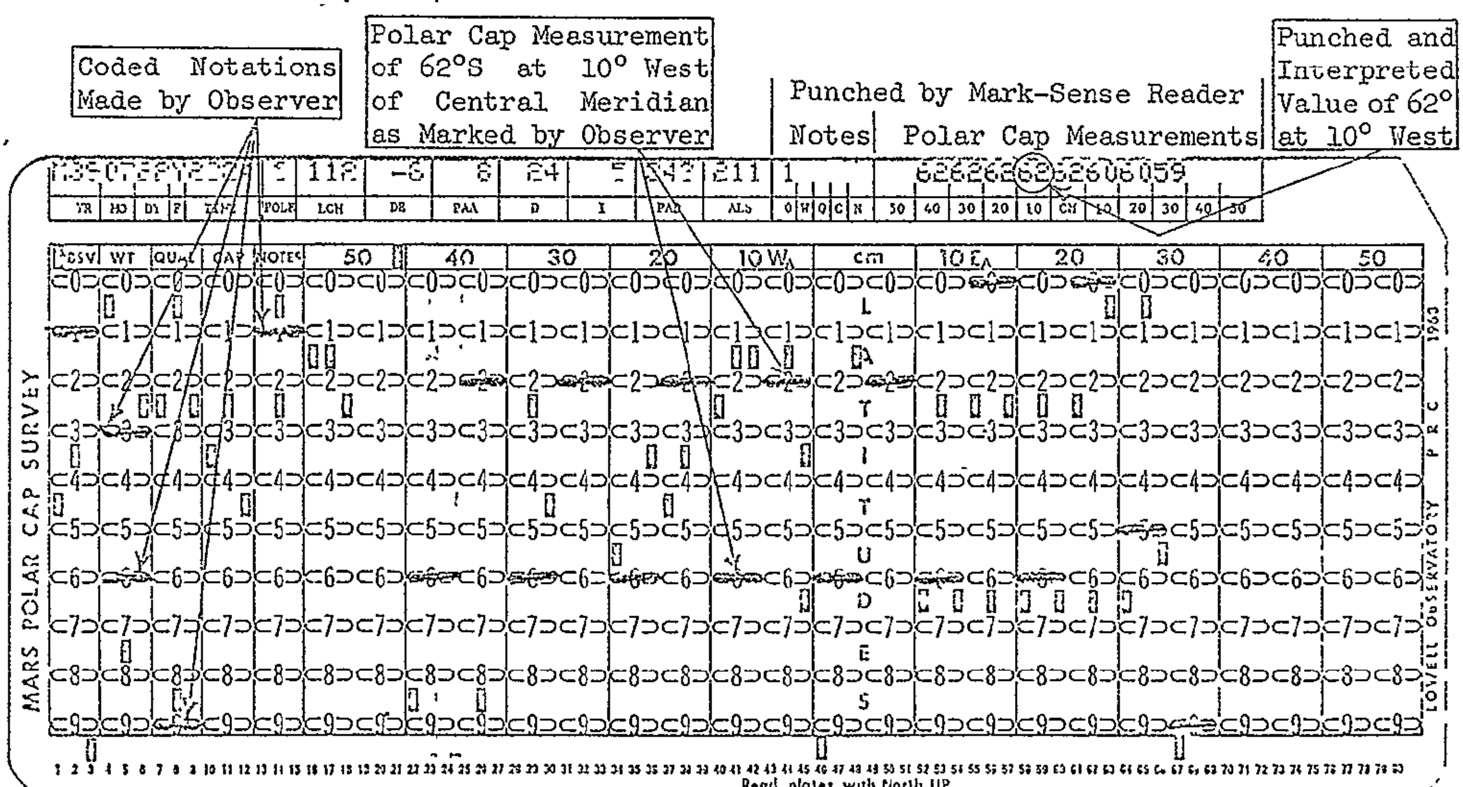
Figure 4.

MARK-SENSE COMPUTER CARDS

PREPUNCHED CARD, PRIOR TO MEASURING POLAR CAP



CARD IS MARKED FOR NOTES AND MEASUREMENTS--THEN PUNCHED BY MARK-SENSE READING MACHINE.



COMPLETED CARD, READY TO FEED INTO VARIOUS COMPUTER PROGRAMS

TABLE II. Code for first five columns of mark-sense data cards shown in Figure 4. Other mark-sense columns contain polar-cap boundary readings.

OBSERVER

0 - Baum
1 - Fischbacher
2 - Martin
3 - de Groff
4 - Jones
5 - Boyce
6 - Smith
7 -
8 -
9 -

WEIGHT

Resolution (Readability)
0 - Worthless cap; visible
1 - Poor; limits questionable
2 - Average quality
3 - Excellent

Orientation
4 - Estimate (polar cap)
5 - Surface
6 - Based upon trail

Observable limitations
7 - Cap is not visible
8 - Cap visible, but beyond recordable longitudes

 - Time accuracy in question

QUALIFICATIONS

0 - Worthless plate; blank
1 - Image diameter very small
2 - Poor processing or handling
3 - Surface markings very faint
4 - Thin images; underexposed
5 - Dense images; overexposed or daylight
6 - Cap lacks contrast
7 - Seeing reported poor
8 - Focus bad
9 - Trail plate

CAP NOTES

0 - Suspected cloudiness or "polar hood"
1 - Irregularities on cap's edge
2 - Peninsular segment(s) at edge of cap (included in measurements)
3 - Island separation at edge of cap; "Mountains of Mitchel," etc. (excluded from measurements)
4 - Bisected cap; trisected, etc.
5 - Bright spots (areas) within cap
6 - Dark spots (areas) within cap
7 - Dark band at periphery of cap; "Melt band"
8 - Bright band at periphery of cap
9 - Recorded cap is not continuous to the limb (pole) at all longitudes

GENERAL NOTES

0 - Further notes on card

Surface
1 - Good surface detail; recommended for mapping or studying surface
2 - Unusual light markings
3 - Unusual dark markings

Atmosphere
4 - Planet-wide "haze"; much of the surface not apparent
5 - Belt phenomena; interesting limb clouds (white) which may indicate diurnal tendencies
6 - Extensive dust clouds; storms
7 - Localized clouds
8 - Identifiable "W" clouds

9 - Observational notes exist apart from time log

settings and polar-cap boundary readings. The cap tends to appear slightly larger on a dense image or on one exposed during poor seeing. Near the limb, the cap is dimmer and therefore may look slightly narrower than it should; but as remarked above, measurements were not made near the limb. When readings made from poor plates are compared with those made from good plates, various sources of error such as those just described are found to have contributed surprisingly little to the errors of measurement. We have no way of determining residual systematic errors due to image quality and photographic effects, but the lack of an apparent dependence upon various degrees of such effects would suggest that the systematic errors are probably not large. They are suspected of being comparable with the random errors discussed in the next section.

After readings had been marked with pencil on the IBM cards, the cards were put through a "mark-sense" reader that transformed the pencilled information into punched holes. The fully-punched cards were then run through an interpreter so that the punched data were printed out along the top edge of the card following the plate identification and ephemeridian data that were already there.

DATA REDUCTION AND ANALYSIS

Data from the various apparitions of Mars were first dealt with separately. A computer program was written to combine the data from each apparition into a tabulation of mean latitudes of the boundary for various seasonal intervals. The Martian year was divided into thirty-six such intervals, each 10° wide in terms of the areocentric longitude of the Sun (ALS). Plates taken during any particular apparition typically spanned several of these 10° seasonal intervals.

Table III is a sample page from the computer printout. Specifically, it represents mean values formed from south pole readings on plates taken in 1939 during the ALS interval from 205° to 214°. This particular printout included data from plates whose image resolutions (readabilities) varied from poor (weight 1) to excellent (weight 3) and whose orientations in the projection plate reader ranged in certainty from those based upon the polar cap itself (weight 1, punched 4 on cards according to Table II) to those that were based upon a trailed image (weight 3, punched 6 on cards). In other words, the sample page in Table III includes all readable plates from the particular time interval specified.

All together, the printout comprised 213 pages similar to the sample page reproduced in Table III, and a complete copy of all 213 pages was submitted earlier to the Jet Propulsion Laboratory.

In Table III the mean latitude of the south polar-cap boundary is given at each of 36 areographic longitudes, 10° apart. For this

TABLE III

SAMPLE PAGE OF POLAR-CAP BOUNDARY PRINTOUT

MARS POLAR CAP BOUNDARIES S POLE

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA AUGUST 17, 1968

1939 OPPOSITION 101 PLATES

SEASON (ALS) LIMITS ENTERED 205 - 214, FOUND 205 - 214.
READABILITY LIMITS ENTERED 1 - 3, FOUND 1 - 3.
ORIENTATION LIMITS ENTERED 1 - 3, FOUND 1 - 3.

LONGI-TUDE	MEAN LATITUDE	MEAN DEVIATION	NUMBER OBSERV.	NUMBER CLOUDS	CAP READABILITY	ORIENTATION WEIGHT
10	62.48	1.15	23	1	2.0	2.9
20	62.70	1.20	23	1	2.1	2.9
30	62.46	1.14	26	1	2.1	2.8
40	62.68	1.26	22	0	2.3	2.7
50	62.64	1.28	25	0	2.3	2.6
60	62.65	1.40	31	0	2.3	2.3
70	62.88	1.50	33	0	2.3	2.3
80	62.68	1.72	34	0	2.4	2.2
90	62.35	1.52	40	0	2.3	2.0
100	61.85	1.09	33	0	2.3	1.9
110	61.91	0.94	34	0	2.3	1.7
120	61.83	1.05	35	0	2.3	1.6
130	61.58	0.95	31	0	2.3	1.5
140	61.54	0.93	28	0	2.2	1.6
150	61.42	0.96	26	0	2.1	1.5
160	61.60	0.84	20	0	2.1	1.4
170	61.56	1.06	16	0	2.1	1.4
180	61.46	1.42	13	0	1.9	1.3
190	61.50	1.60	10	0	1.7	1.2
200	61.67	1.63	9	0	1.8	1.3
210	61.67	2.00	6	0	1.6	1.0
220	61.50	2.00	4	0	1.5	1.5
230	60.75	1.63	4	0	1.5	1.9
240	61.00	1.14	7	0	1.5	2.4
250	61.11	1.26	9	0	1.5	2.5
260	60.93	1.06	14	0	1.5	2.6
270	60.93	1.06	14	0	1.5	2.6
280	60.87	1.00	16	0	1.7	2.8
290	60.73	1.01	15	0	1.7	2.9
300	60.78	0.69	18	0	1.8	2.8
310	60.65	0.62	23	0	1.9	2.9
320	60.77	0.59	26	1	1.8	2.9
330	60.88	0.54	26	1	1.8	2.9
340	61.23	0.71	26	1	1.9	2.9
350	61.77	1.20	26	1	1.9	3.0
360	62.11	1.29	28	1	1.9	3.0

particular season, the latitude of the south cap boundary is seen to average about 61.6°, and the run of the tabulated values indicates that the center of the cap is then about one degree eccentric with respect to the assumed Martian pole. The third column of Table III gives the mean deviation among the readings from which each of the means in the second column was formed, and the fourth column gives the number of plates that entered into each mean. It is interesting to note that the average value of the mean deviations is only 1.18°. This is rather remarkable when the heterogeneous character of the photographic material is considered, and when the one-degree half-valve of the coordinate grid steps is allowed for. Although Table III represents a particularly favorable season for Martian observation, the mean deviations found in less favorable seasons were only slightly larger. Ten particular plates were picked out for reading by five different people, so that the dependence upon human judgment could be evaluated. The two most experienced observers, who between them read all the plates, differed from one another an average of 2.6 degrees on individual readings, but differed systematically only about 1.3 degrees. Less experienced observers scattered somewhat more but did not disagree systematically by larger amounts. Departures from a mean would be half of these values.

Another computer program was written in order to plot the growth and decay curves of each of the two polar caps at each of the thirty-six meridians. The computer also plotted for each cap an averaged curve representing all meridians combined. Attached to the end of this report are the averaged curves for both caps, together with south-cap curves for the thirty-six individual meridians. Although the curves for the individual meridians resemble the averaged south-cap curve, there are apparently significant differences, and a study of these differences is in progress. The attached curves are based on data from all of the observed apparitions combined.

North-cap curves for the thirty-six individual meridians also resemble the averaged north-cap curve. The north cap, however, seems more erratic in behavior than the south cap and does not have a receding phase that is extended in time in such a way as to lend itself to a meaningful examination of the differences in behavior at the individual meridians. We have therefore not attached the north-cap curves for the individual meridians to this report.

In all of the attached growth and decay curves, three different symbols have been used to indicate the relative weights of the plotted points. A single bar (-) represents points of lowest weight, namely, those based upon fewer than ten readings. A plus sign (+) indicates a point of intermediate weight, namely, one based on 10 to 29 readings. An asterisk (*) represents a point of high weight, namely, one based on more than 30 readings. As mentioned earlier in this report, the receding (melting) phase of both caps is much better represented than the growth phase, because each cap is unfavorably situated (even partly hidden from view) for Earth-based observation during the season when the cap is growing.

Boundaries of the Martian polar caps during their receding phases are diagrammed in Figures 5 and 6. These diagrams are based on the combining of data from all apparitions observed. Between about 55° latitude and the pole, the receding boundaries were found to do nearly the same thing each Martian year. Extensions of the apparent cap below 55° were less regular in behavior and are suspected of being due to an overlaid cloud mantle in late winter.

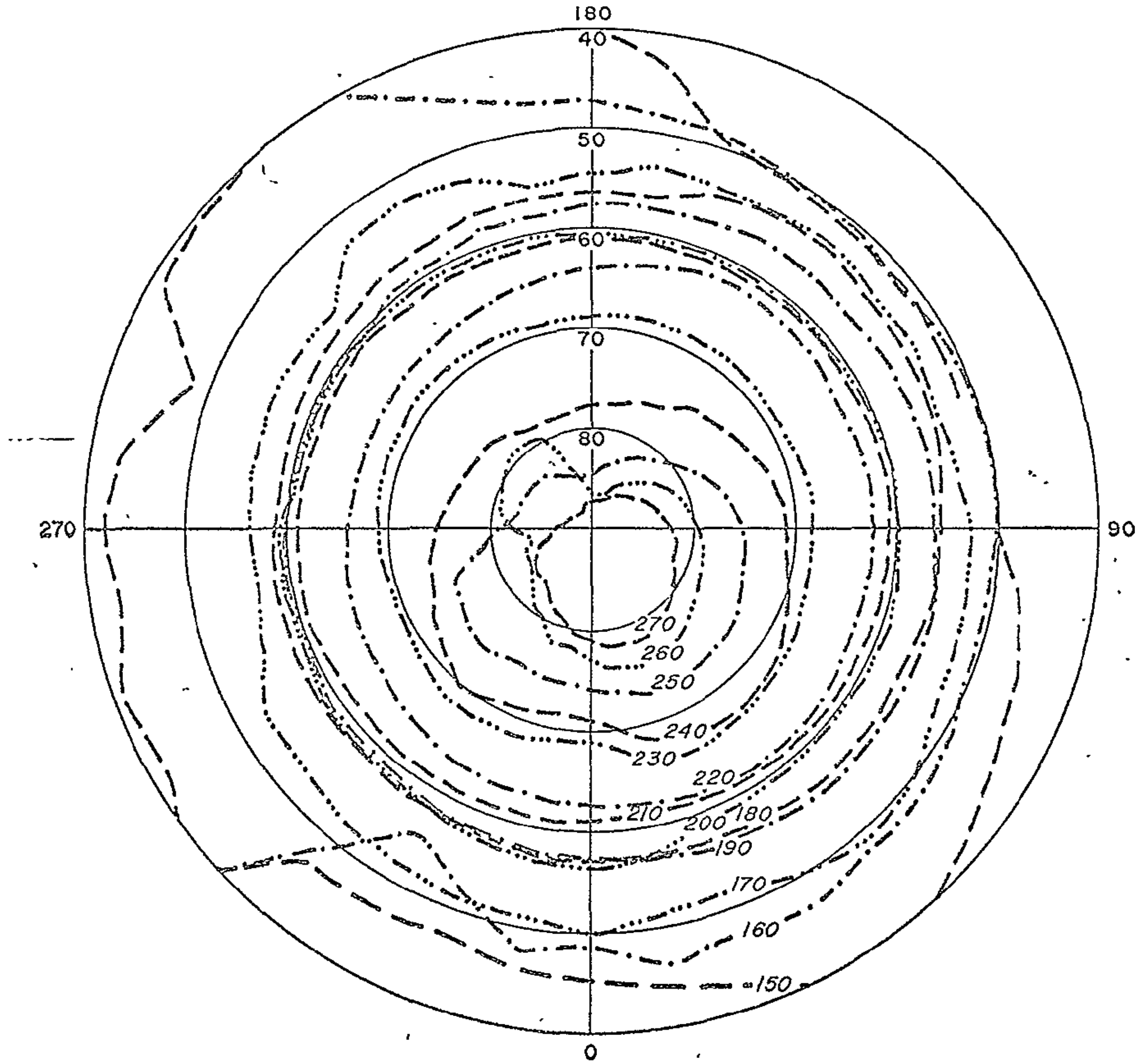
SUMMARY CONCLUSIONS

The two polar caps of Mars are found to differ substantially from one another in their seasonal growth and decay patterns. In both cases, the receding (melting) phase is more observable than the growing phase. The melting of the south cap takes place more gradually than that of the north cap. From the Martian season associated with an areocentric longitude of 180° to 270°, the boundary of the south polar cap is unusually well defined and exceedingly repeatable in its behavior from one Martian year to another. During that time, small but significant differences can be detected among the melt curves for individual meridians, probably due to differences in either surface materials or elevations.

This study was based on more than 3,000 plates in the Lowell Observatory collection. Random errors of measurement introduce uncertainties in mean latitudes of the cap and boundaries that are generally less than one degree. Systematic errors probably vary with the reader and with the season, but they are believed to fall in the range between one and two degrees.

Figure 5.

MARTIAN SOUTH POLAR CAP

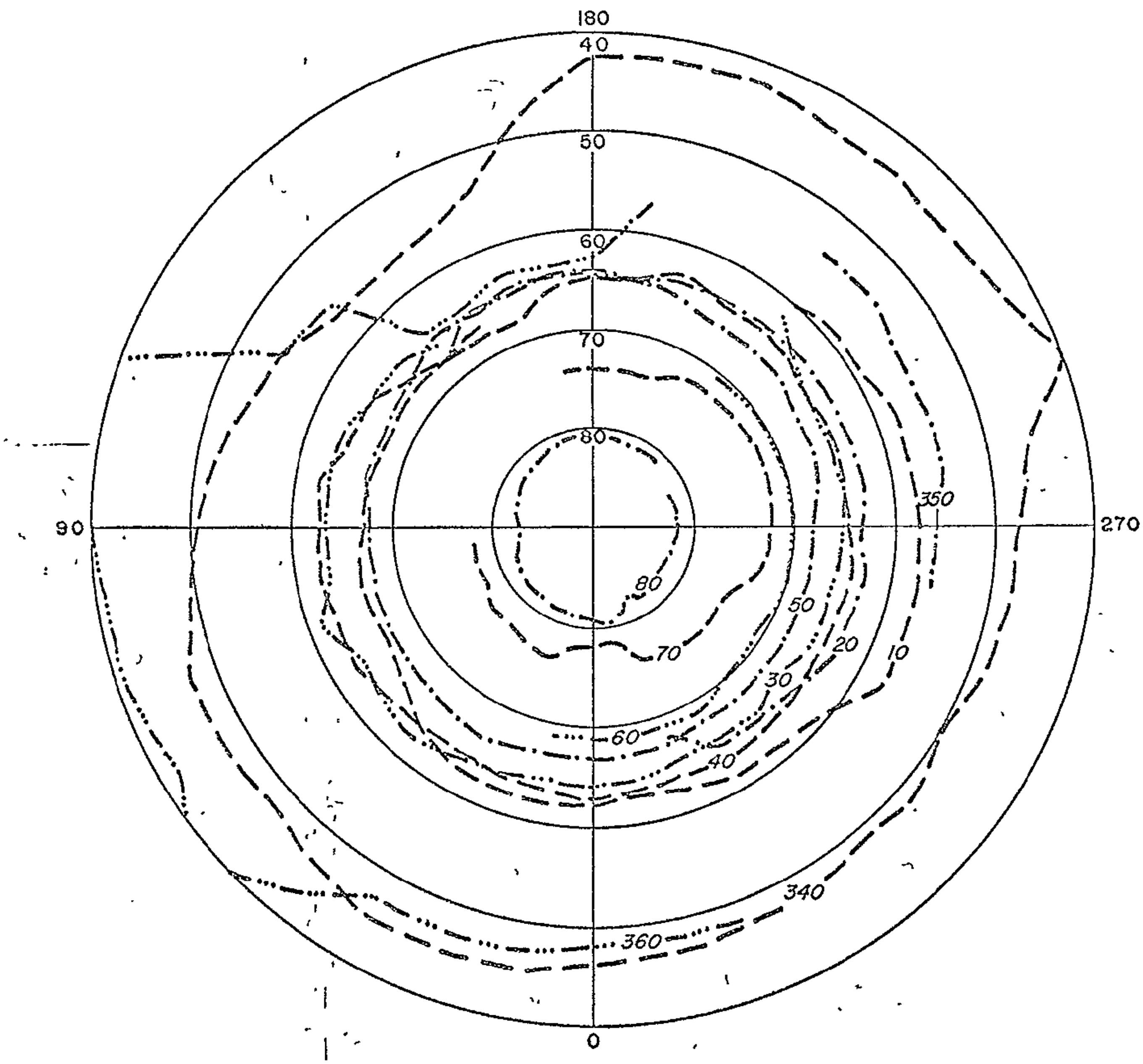


SEASONAL BOUNDARIES OF THE CAP AS VIEWED FROM THE SOUTH

Azmuthal equidistant projection showing circles of latitude at 10° intervals and longitude lines at 0°, 90°, 180°, and 270°. The various types of dashed lines represent the observed boundaries of the south polar cap during its receding phase. Each boundary curve is labeled (in italics) with the "season" of the Martian year expressed in terms of the areocentric longitude of the Sun (ALS) in degrees after the Martian vernal equinox. Data were averaged over 10° intervals centered on the indicated ALS values.

Figure 6.

MARTIAN NORTH POLAR CAP



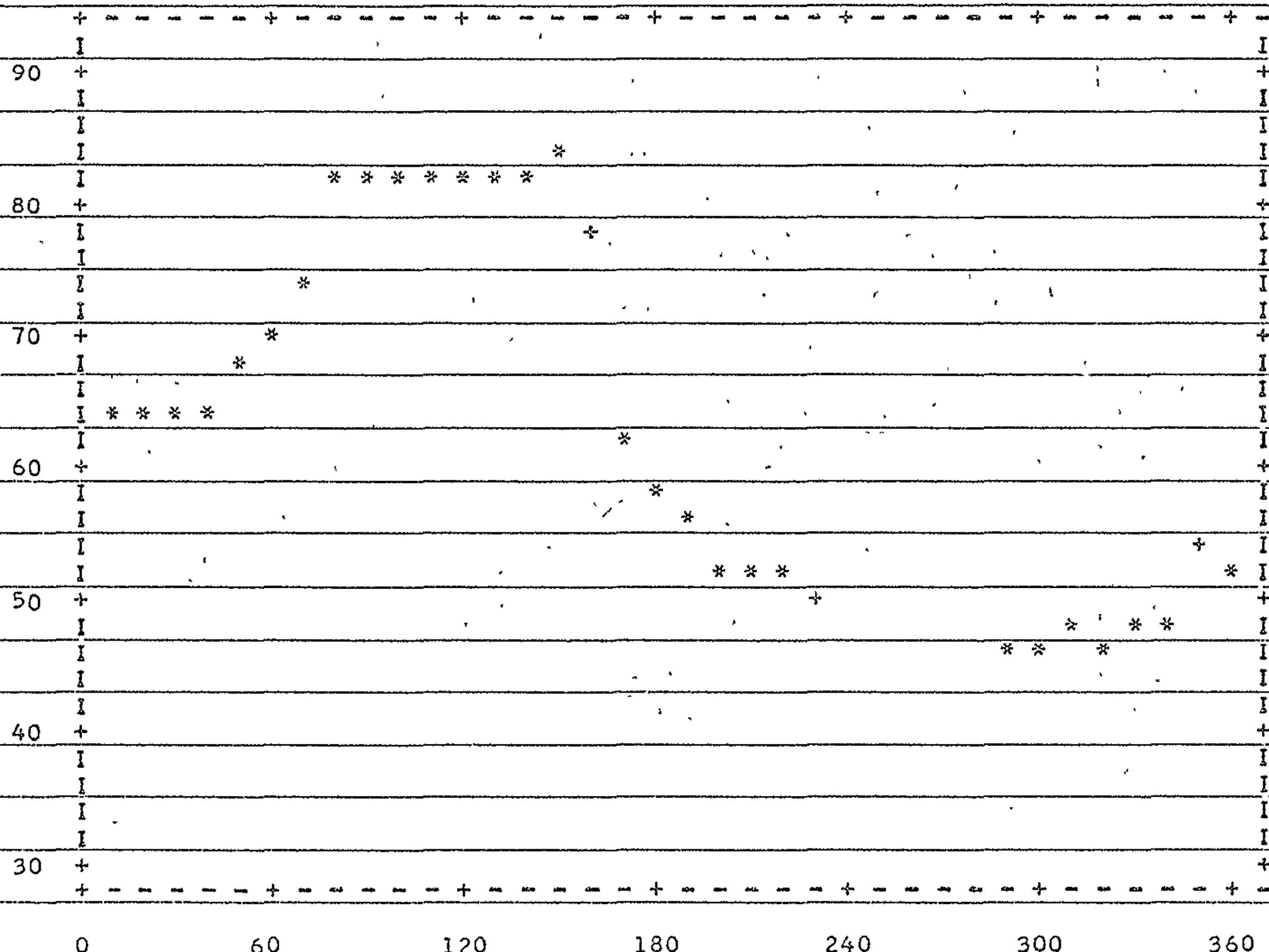
SEASONAL BOUNDARIES OF THE CAP AS VIEWED FROM THE NORTH

Azmuthal equidistant projection showing circles of latitude at 10° intervals and longitude lines at 0°, 90°, 180°, and 270°. The various types of dashed lines represent the observed boundaries of the north polar cap during its receding phase. Each boundary curve is labeled (in italics) with the "season" of the Martian year expressed in terms of the areocentric longitude of the Sun (ALS) in degrees after the Martian vernal equinox. Data were averaged over 10° intervals centered on the indicated ALS values.

LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

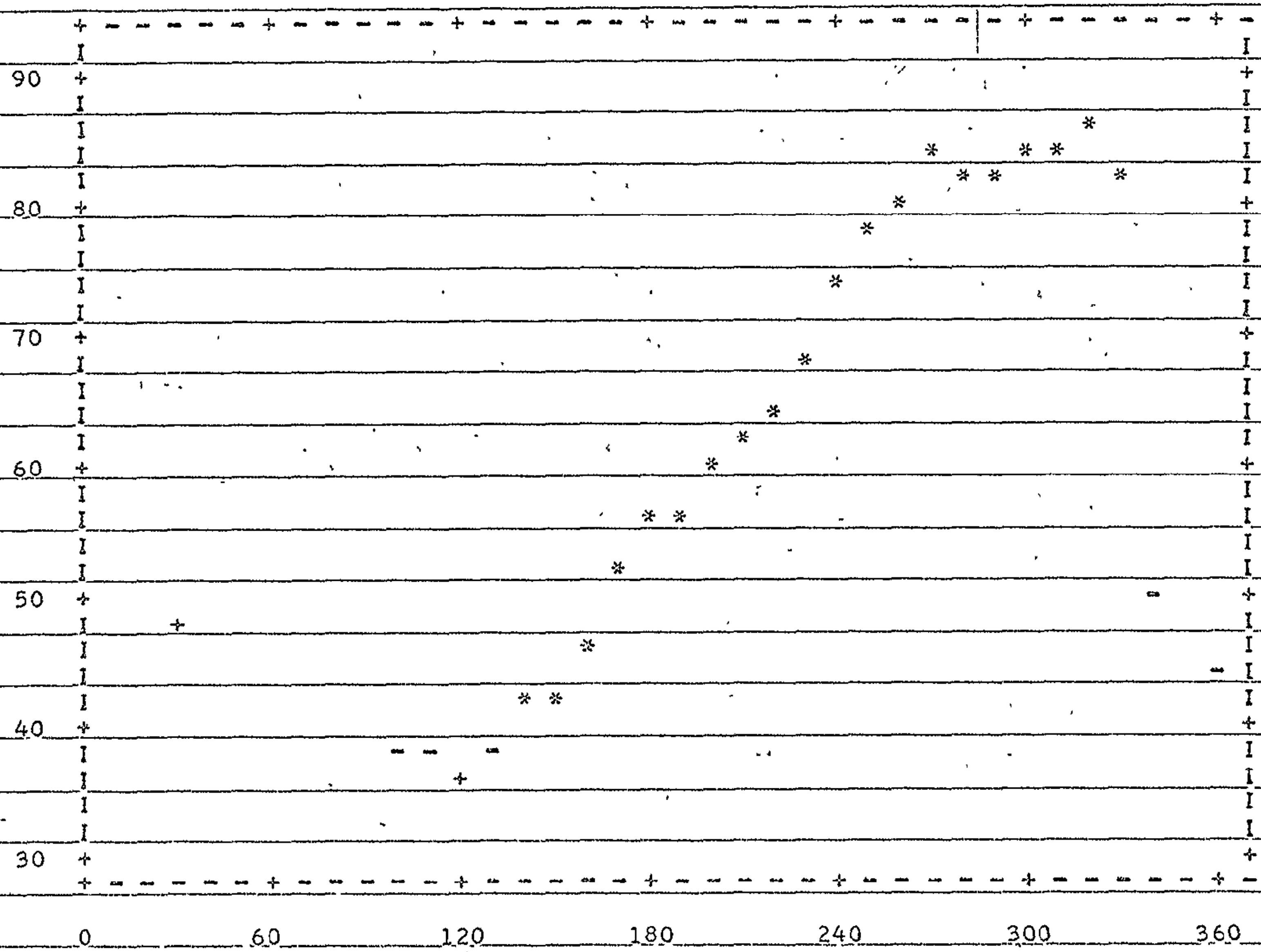
NORTH POLE AT ALL AREOGRAPHIC LONGITUDES



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

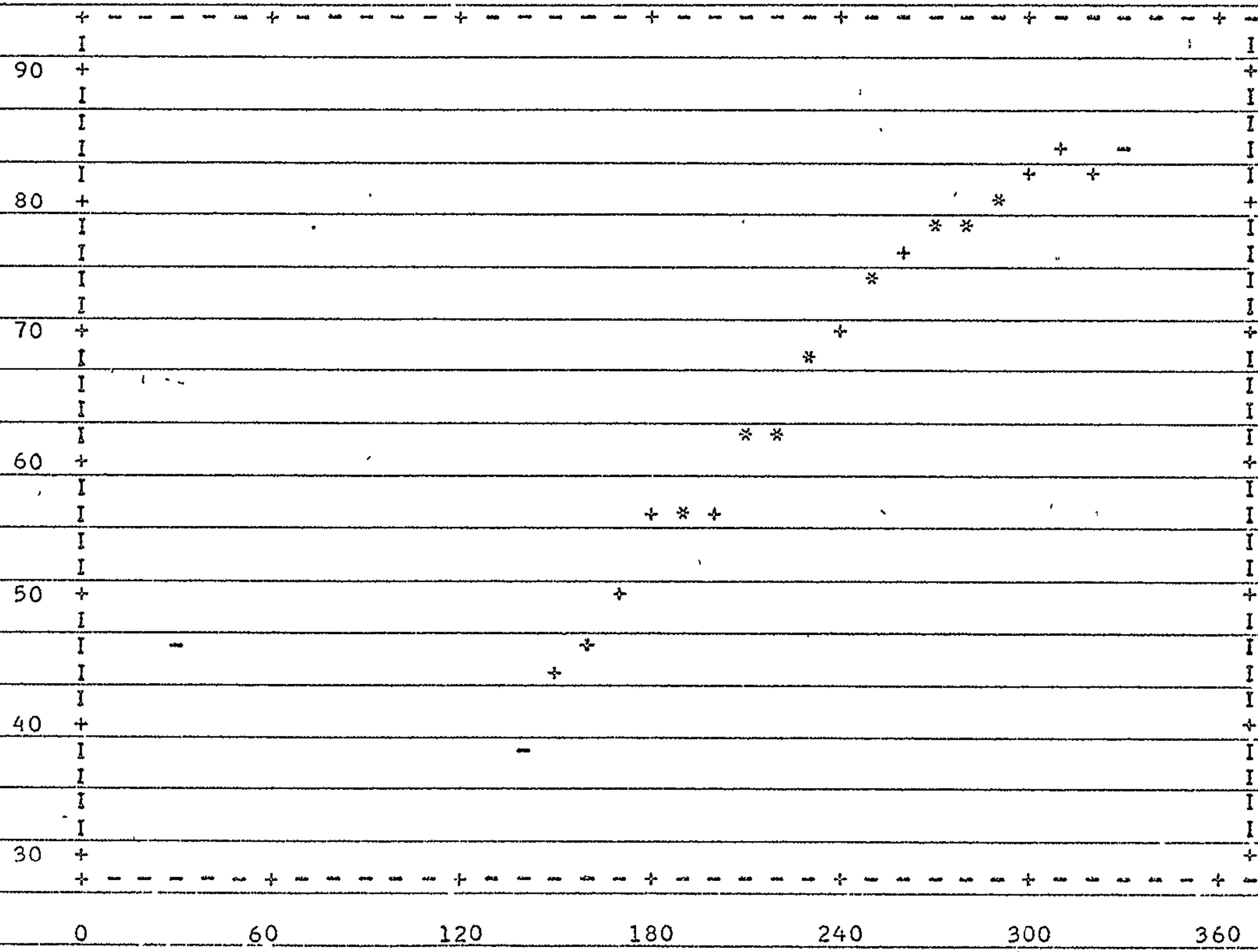
SOUTH POLE AT ALL AREOGRAPHIC LONGITUDES



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY   FLAGSTAFF, ARIZONA   NOVEMBER 27, 1968

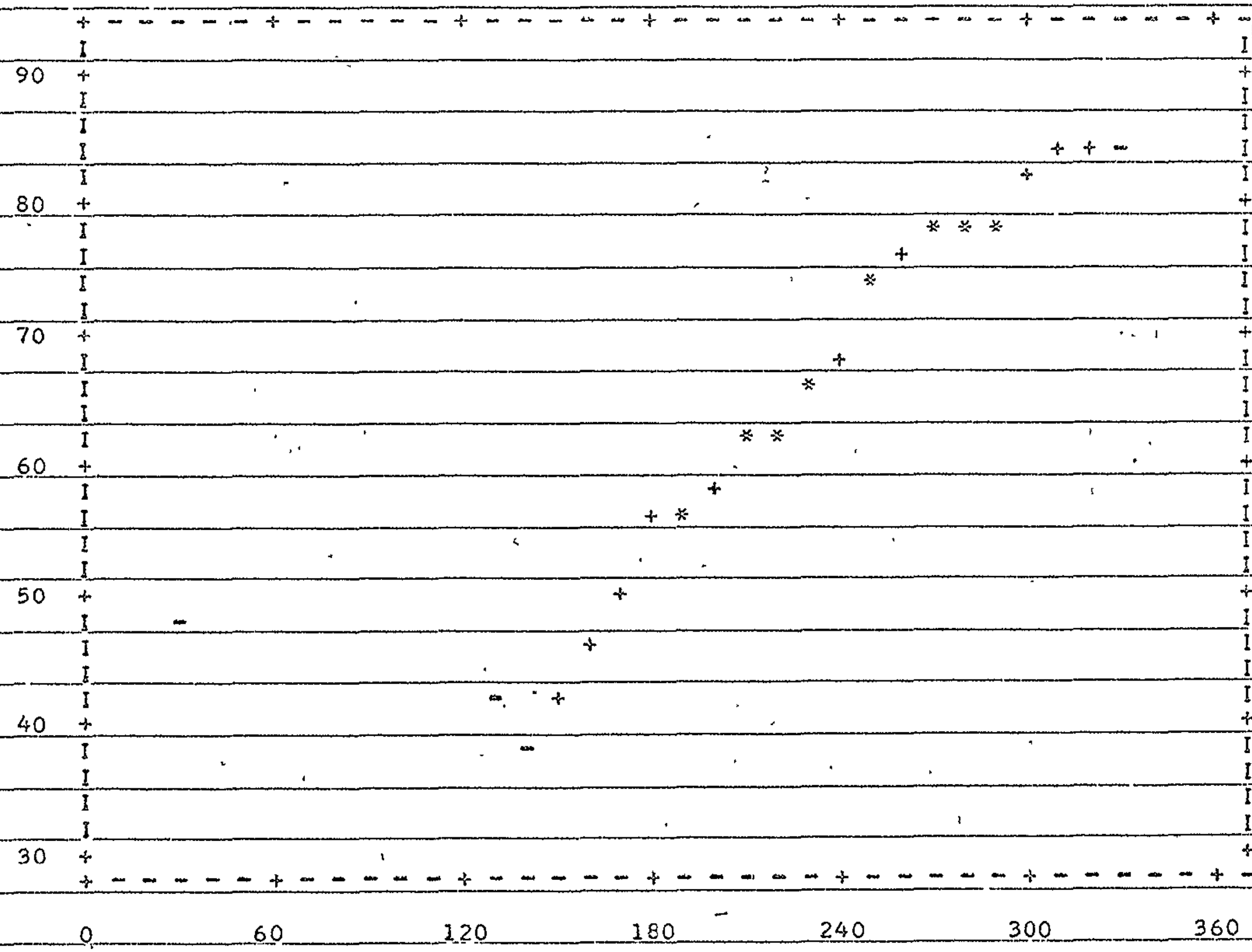
SOUTH POLE AT 10 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

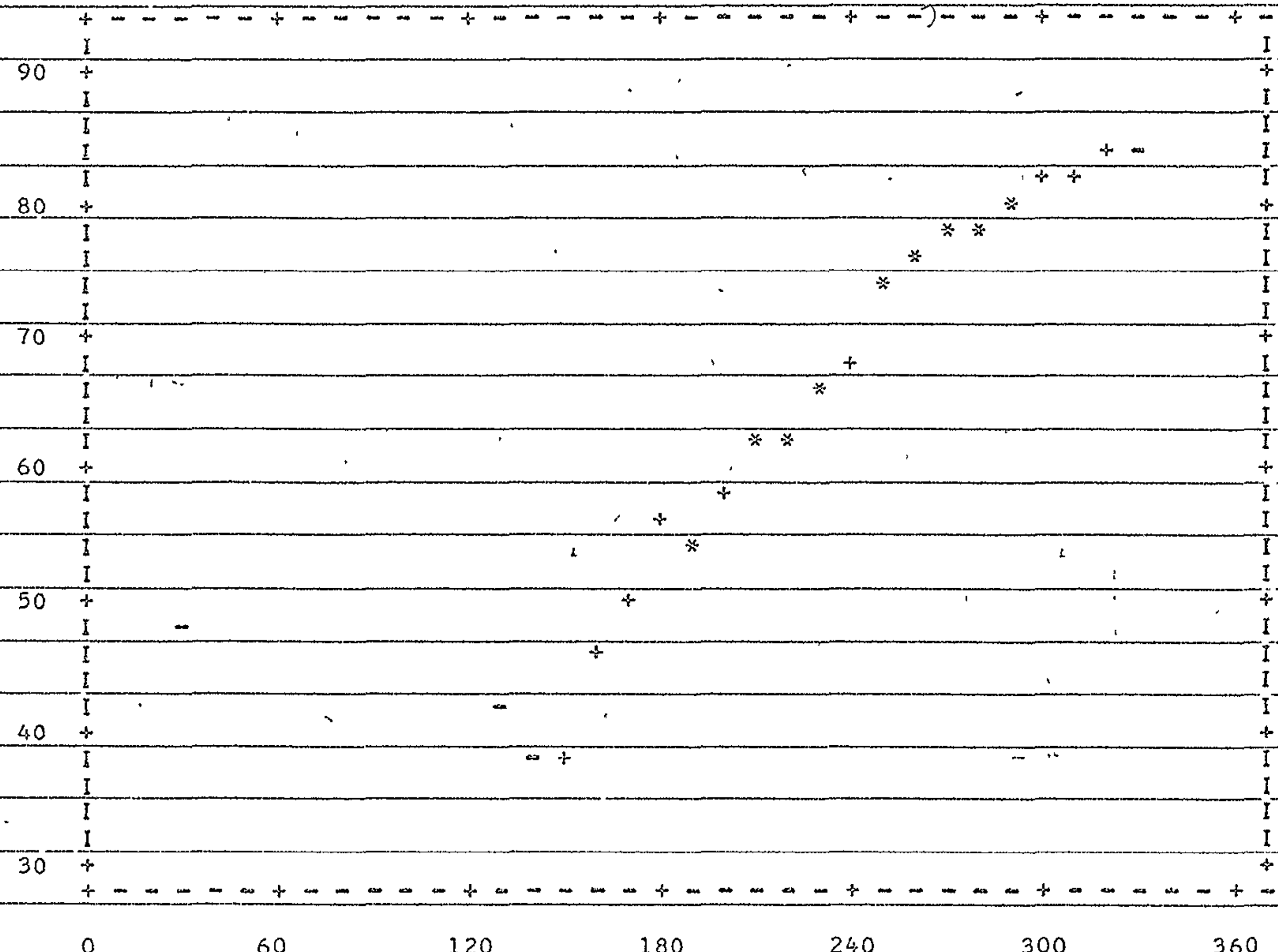
SOUTH POLE AT 20 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

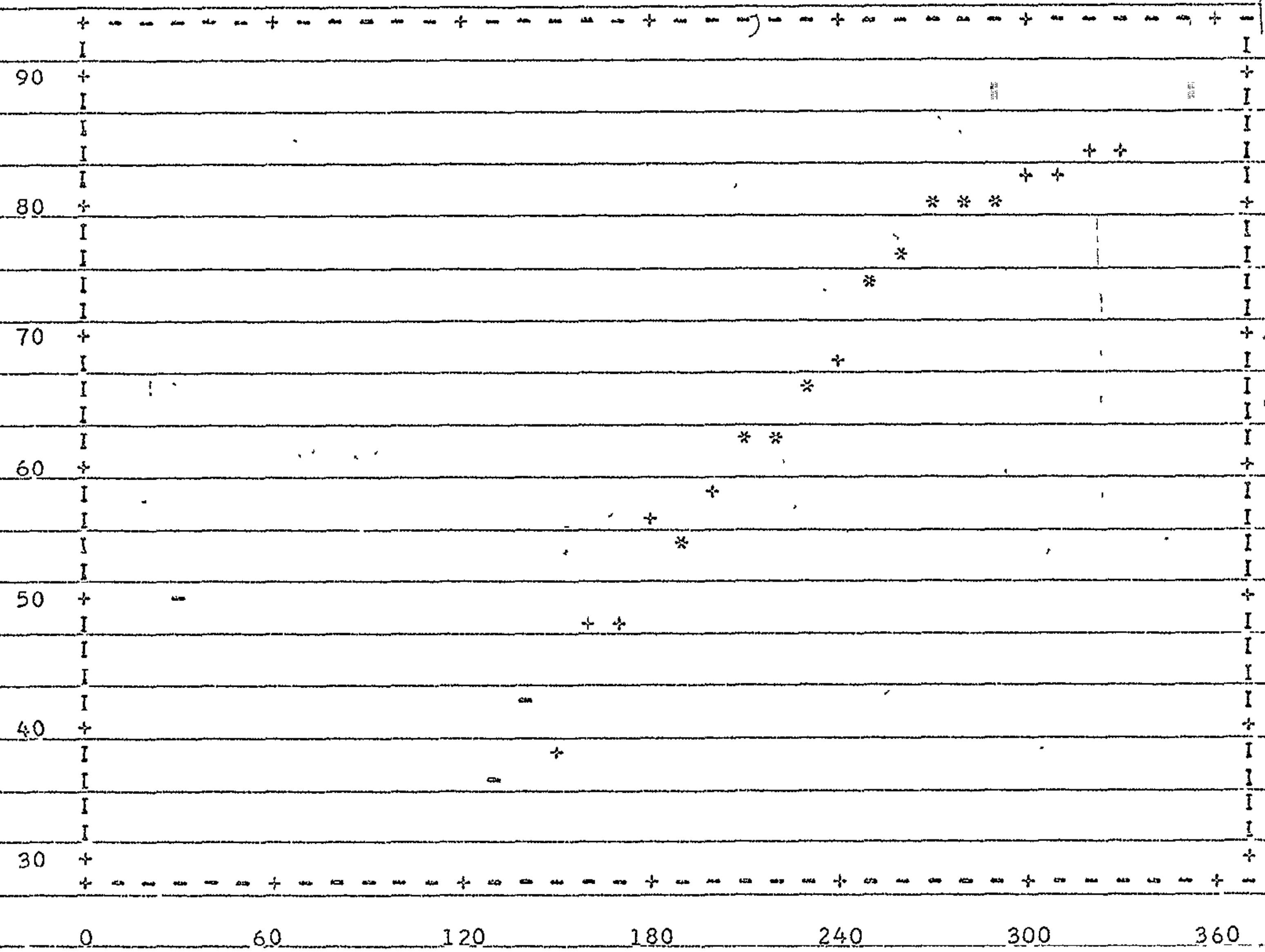
SOUTH POLE AT 30 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

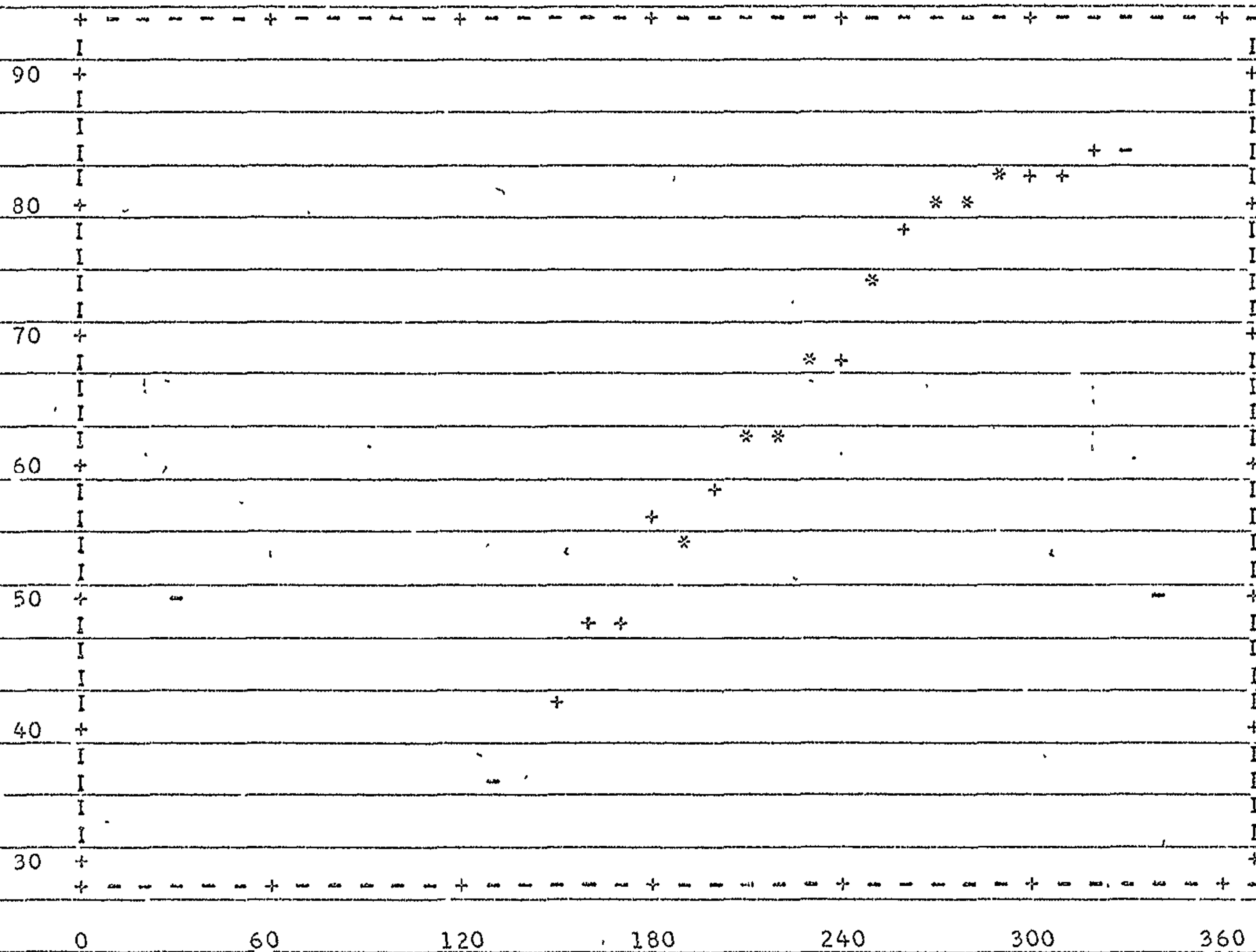
SOUTH POLE AT 40 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

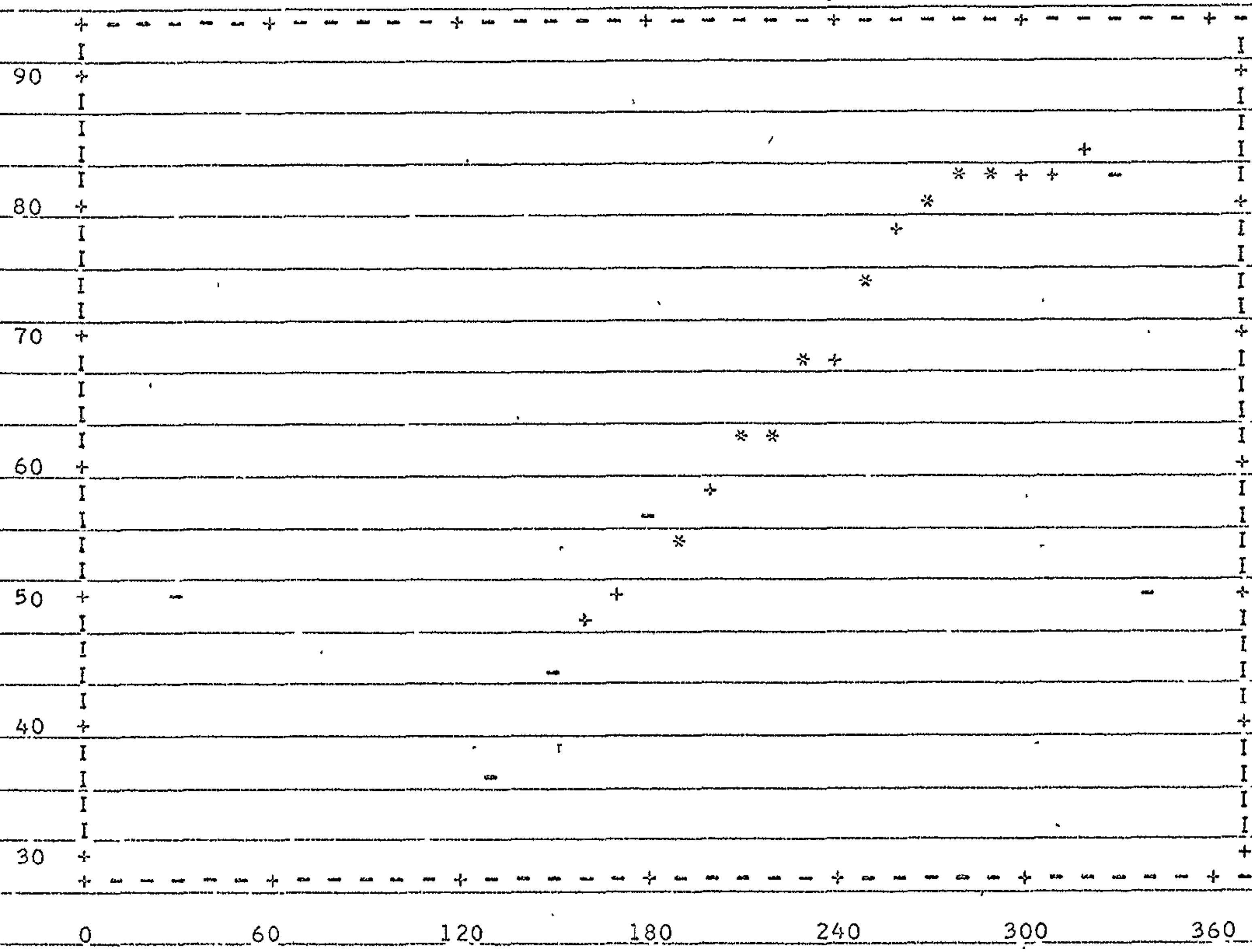
SOUTH POLE AT 50 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

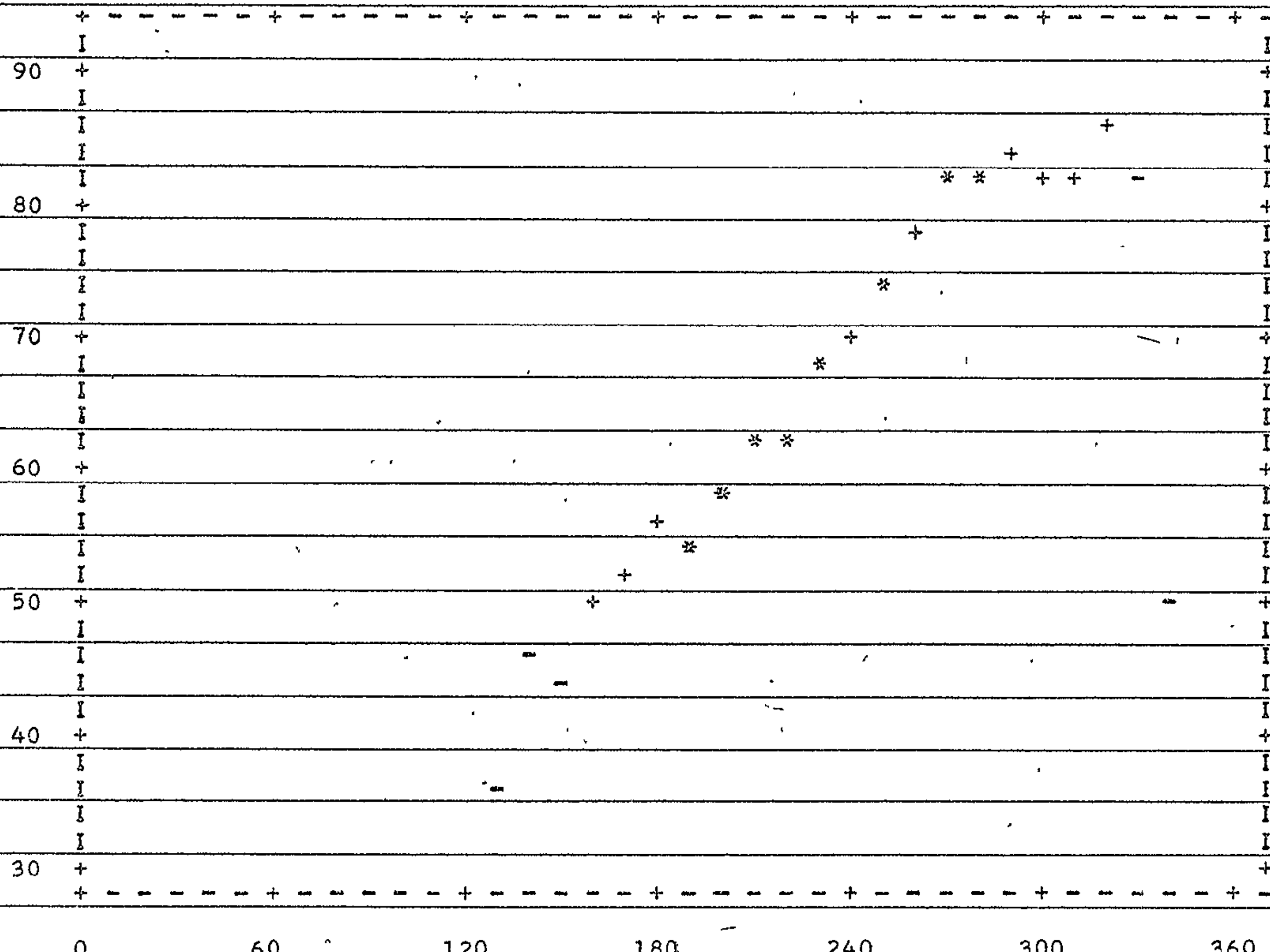
SOUTH POLE AT 60 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY   FLAGSTAFF, ARIZONA   NOVEMBER 27, 1968

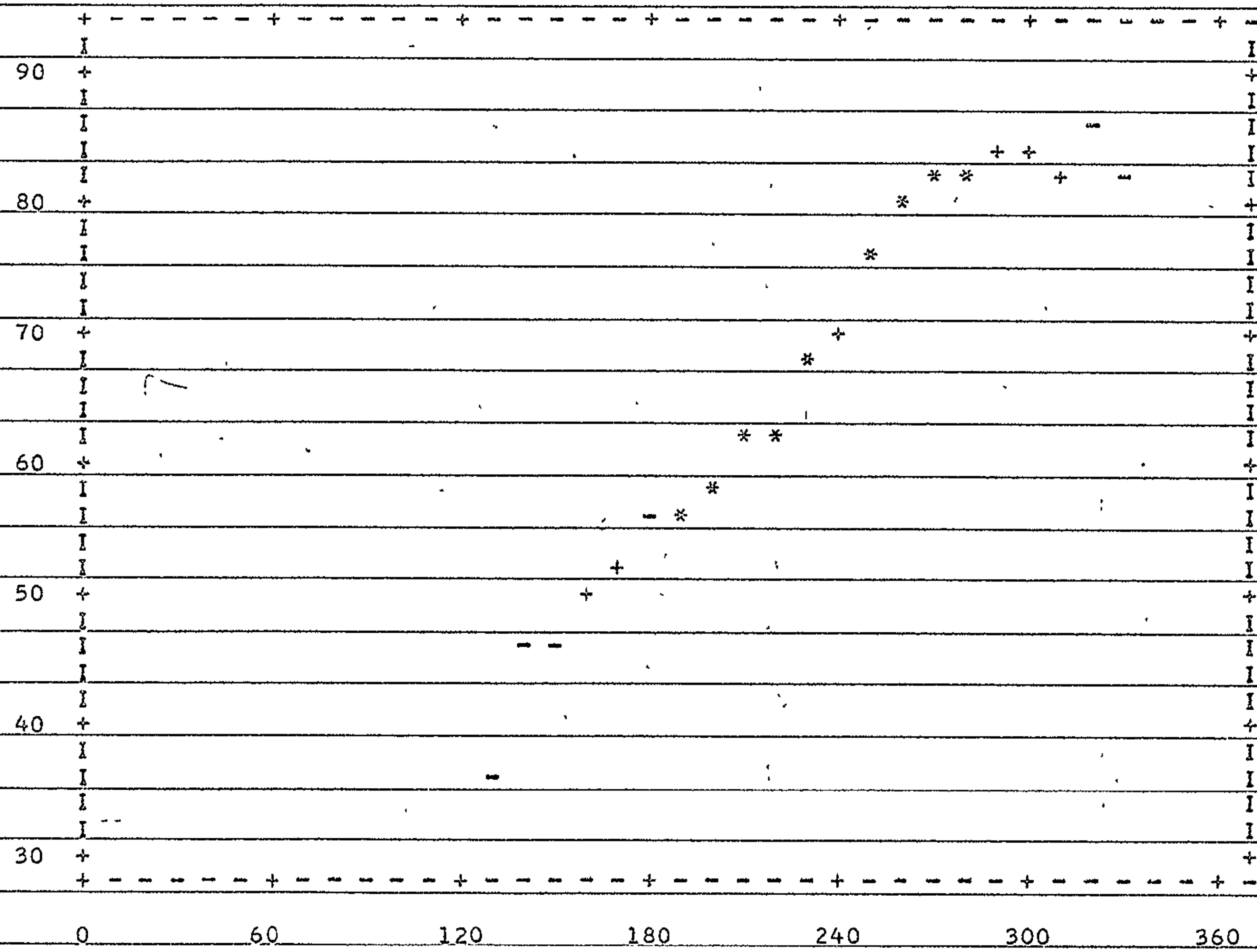
SOUTH POLE AT 70 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

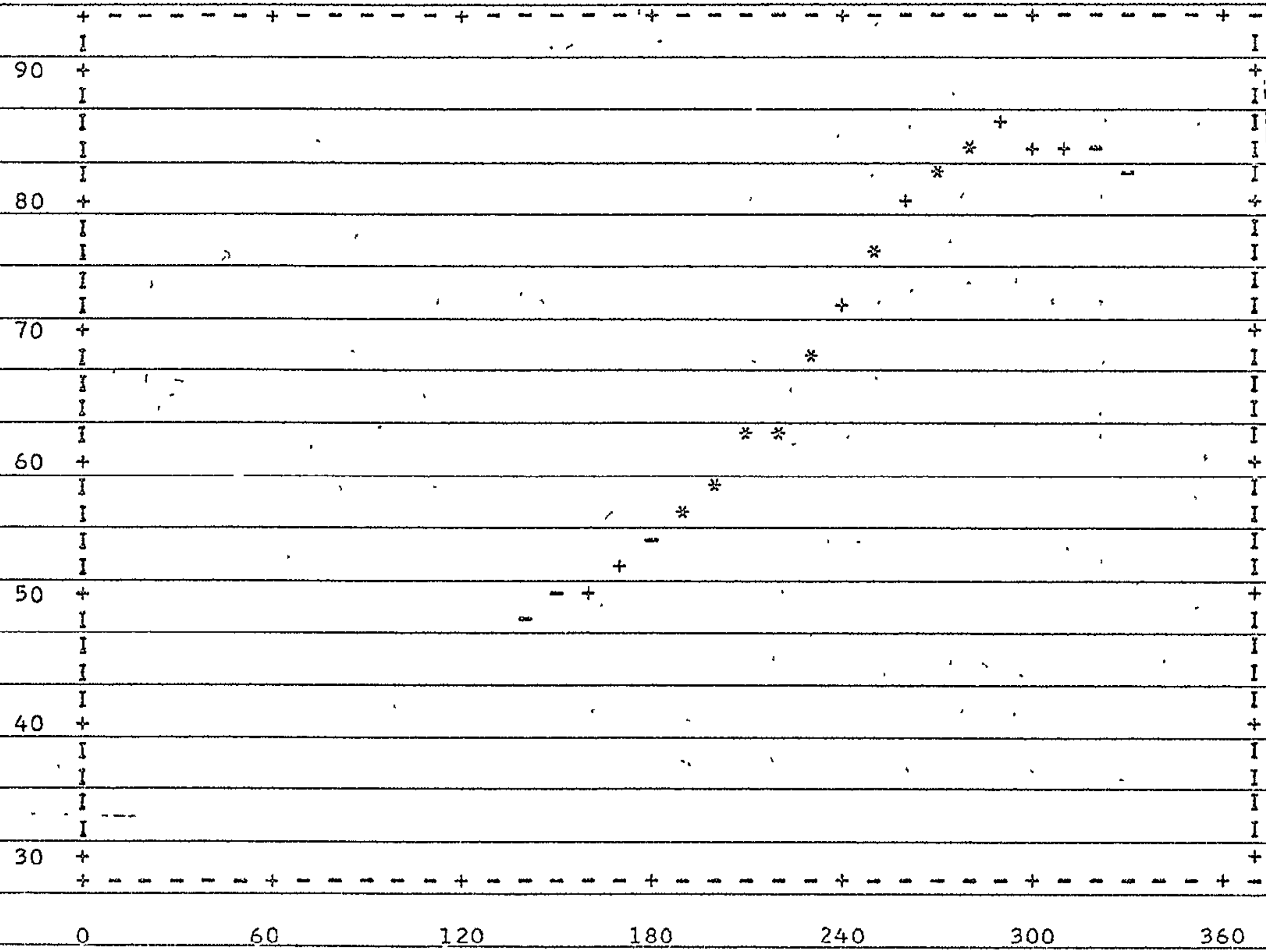
SOUTH POLE AT 80 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY   FLAGSTAFF, ARIZONA   NOVEMBER 27, 1968

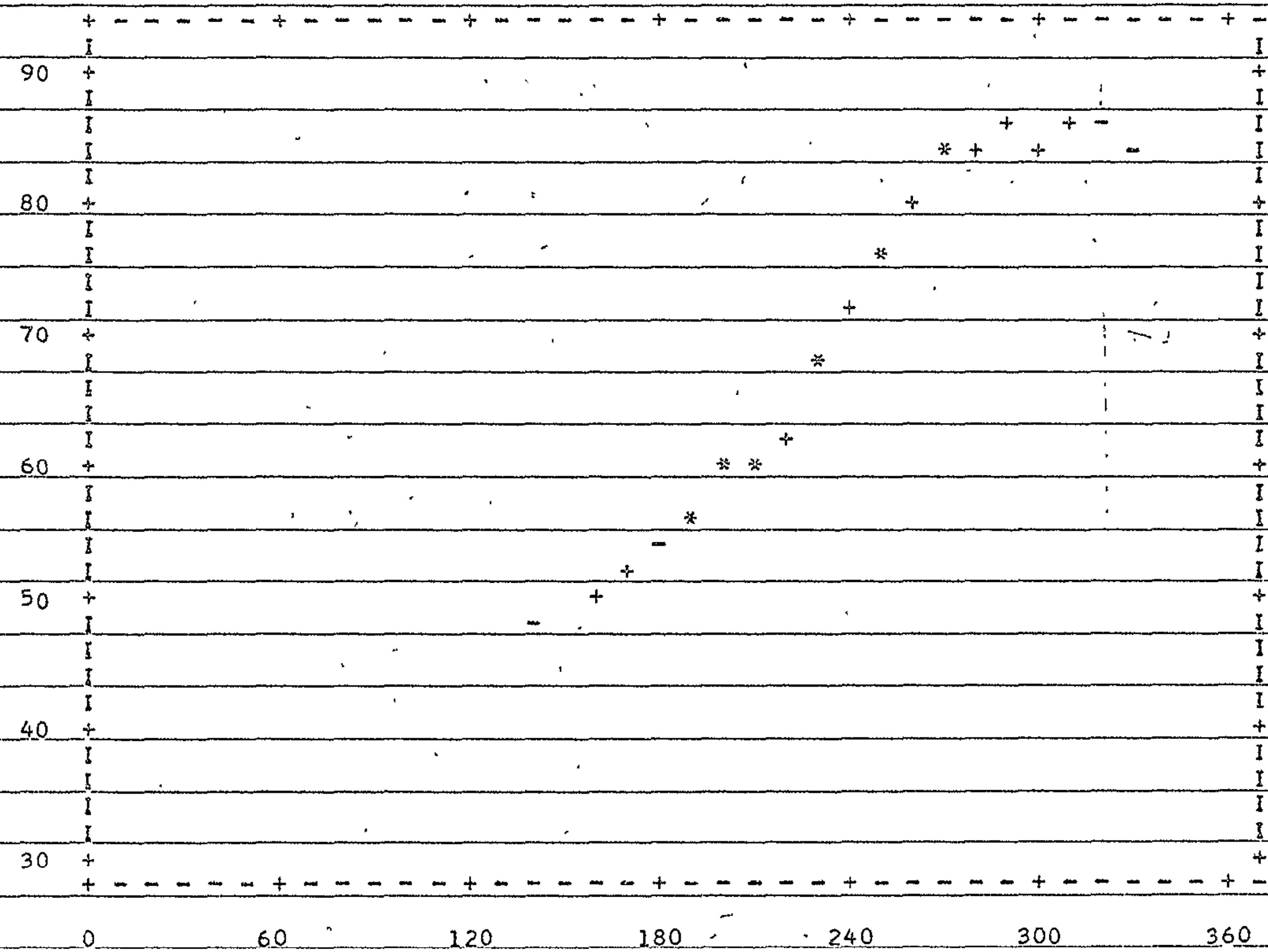
SOUTH POLE AT 90 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

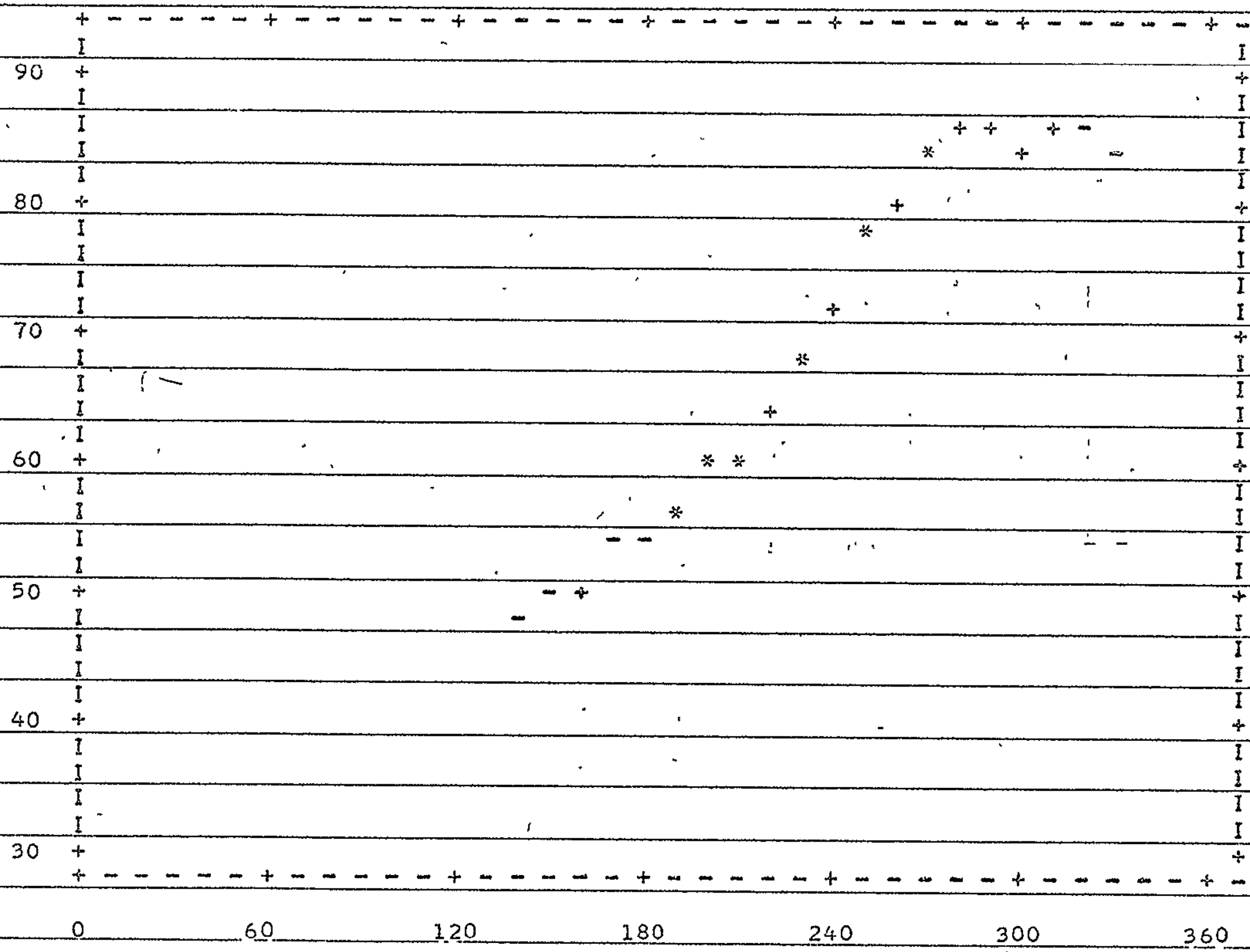
SOUTH POLE AT 100 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

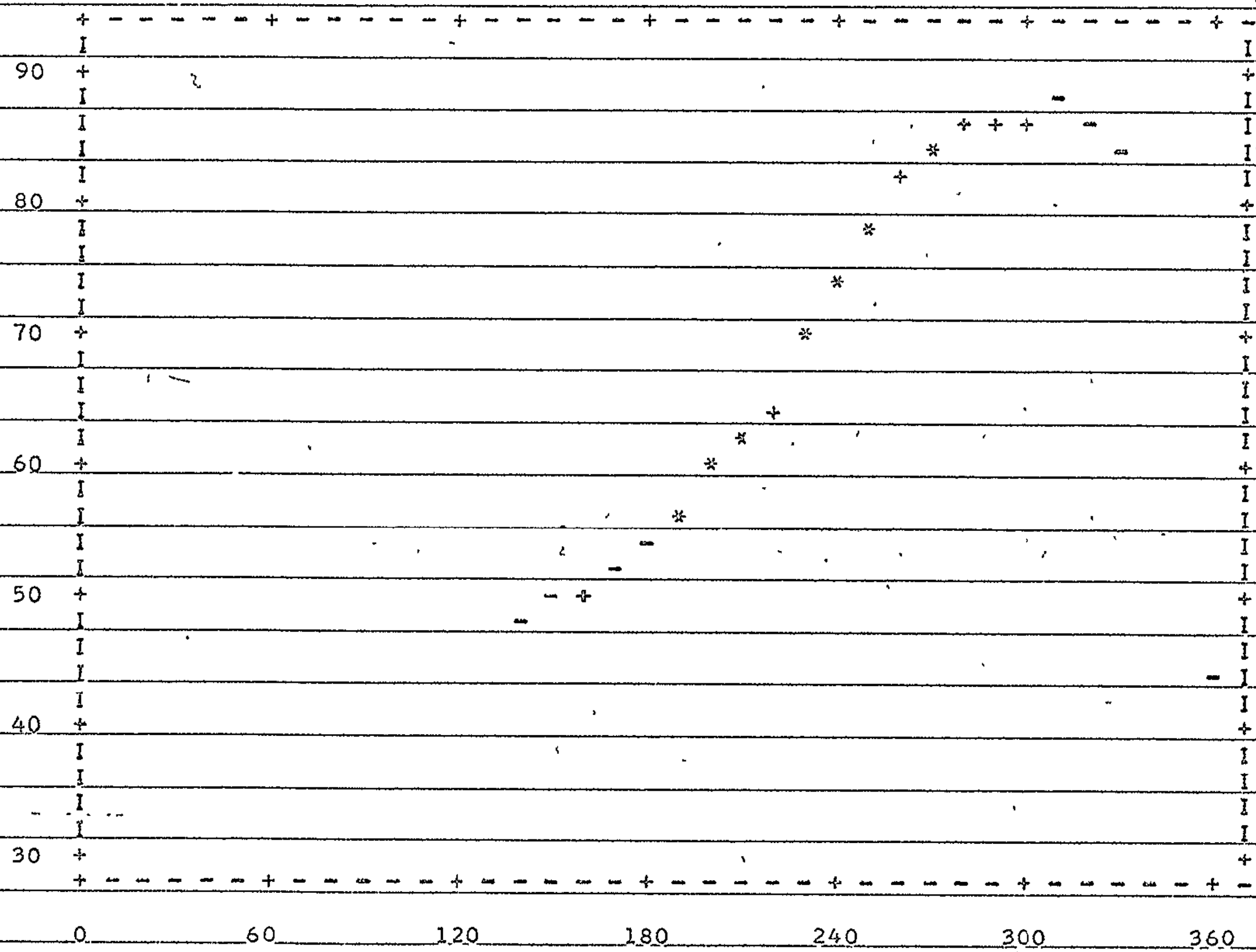
SOUTH POLE AT 110 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

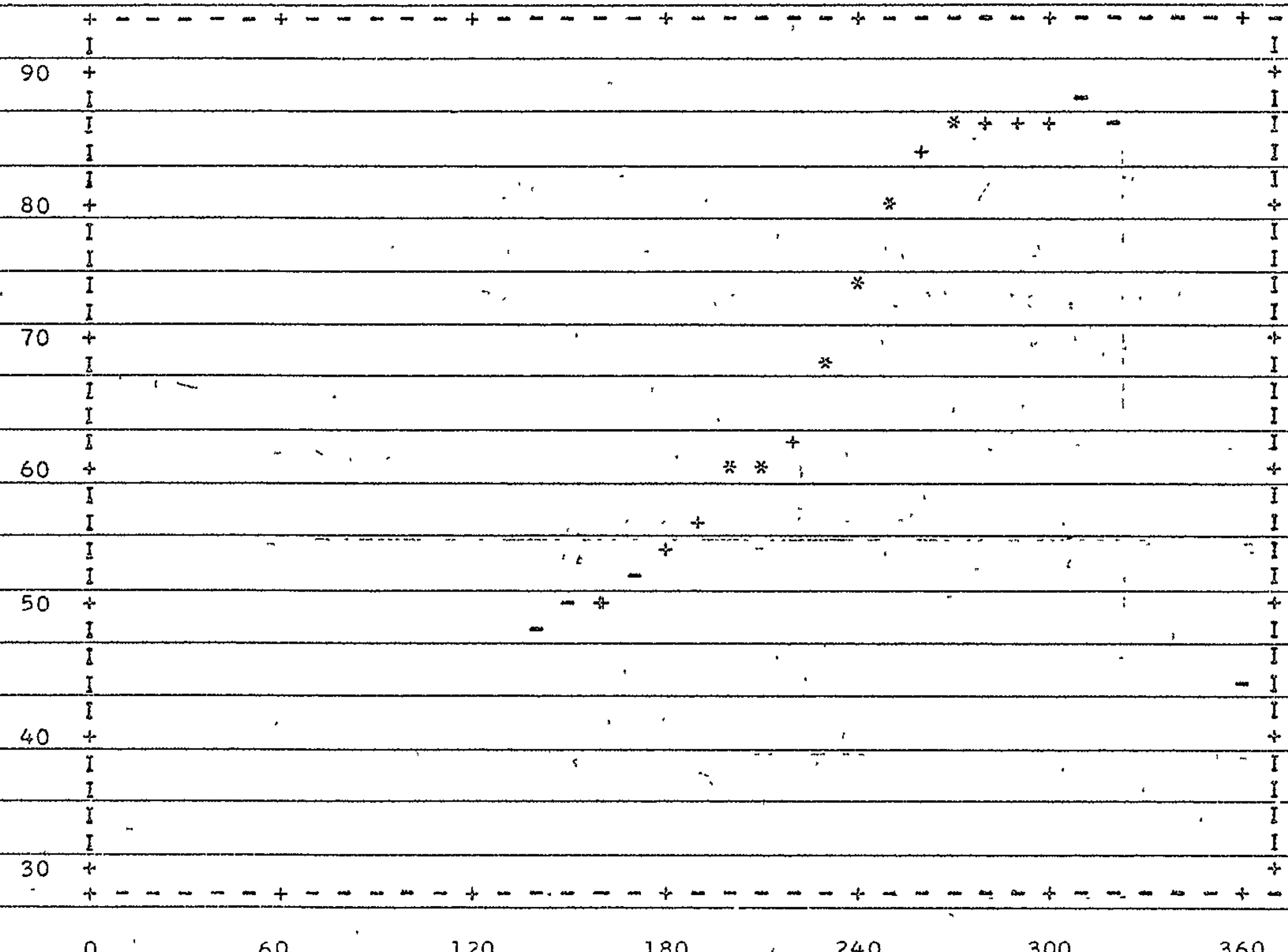
SOUTH POLE AT 120 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

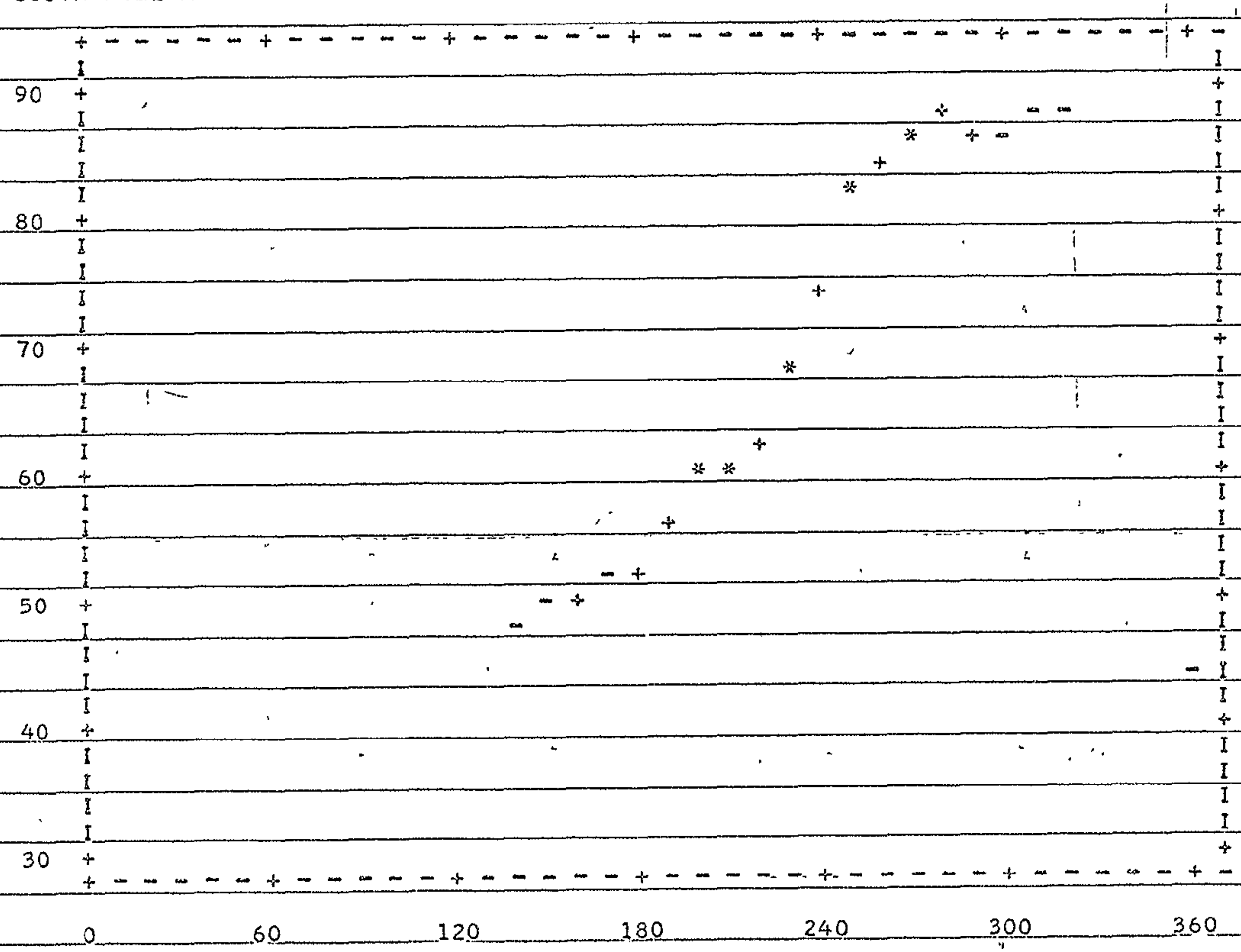
SOUTH POLE AT 130 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

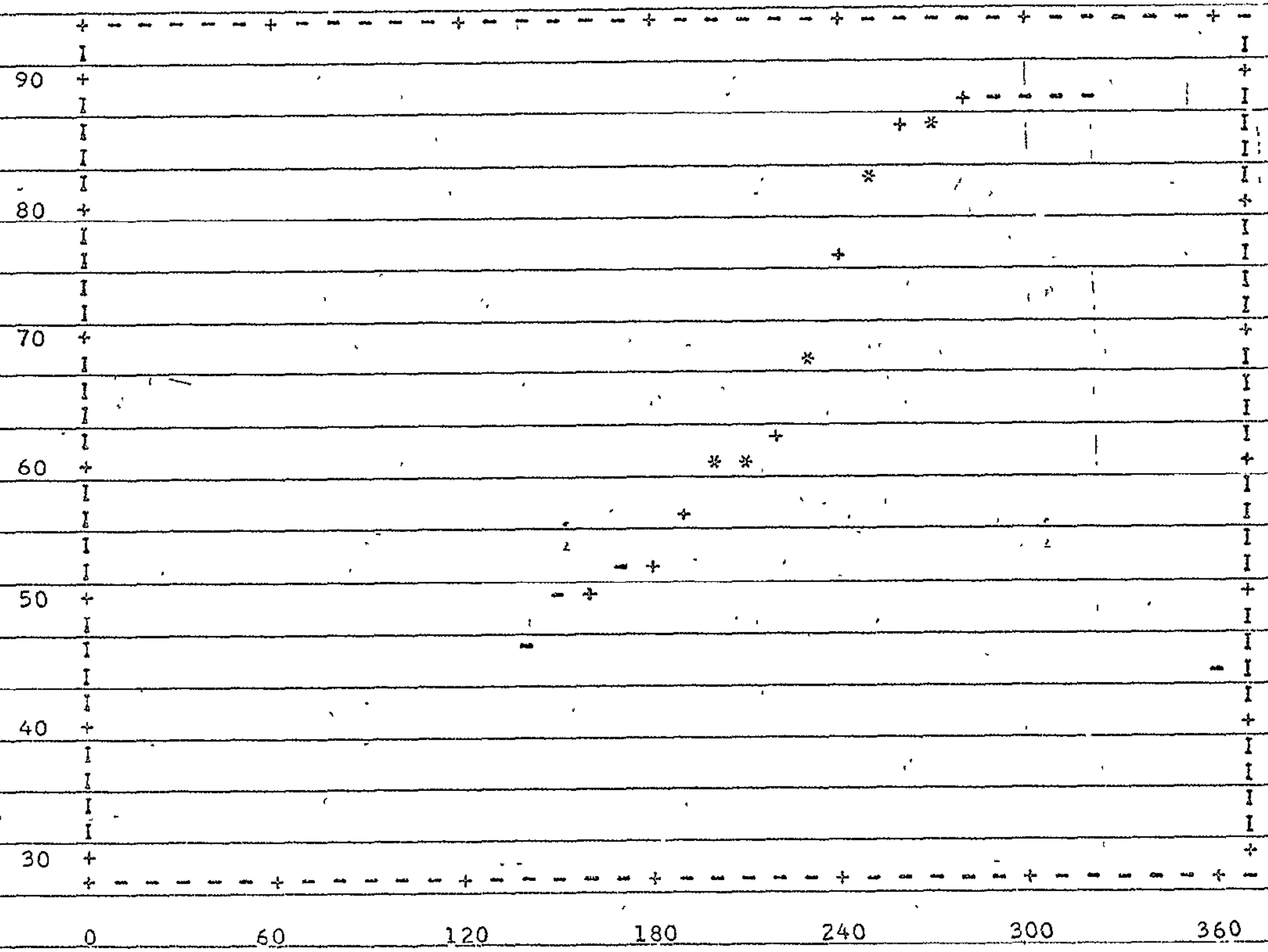
SOUTH POLE AT 140 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

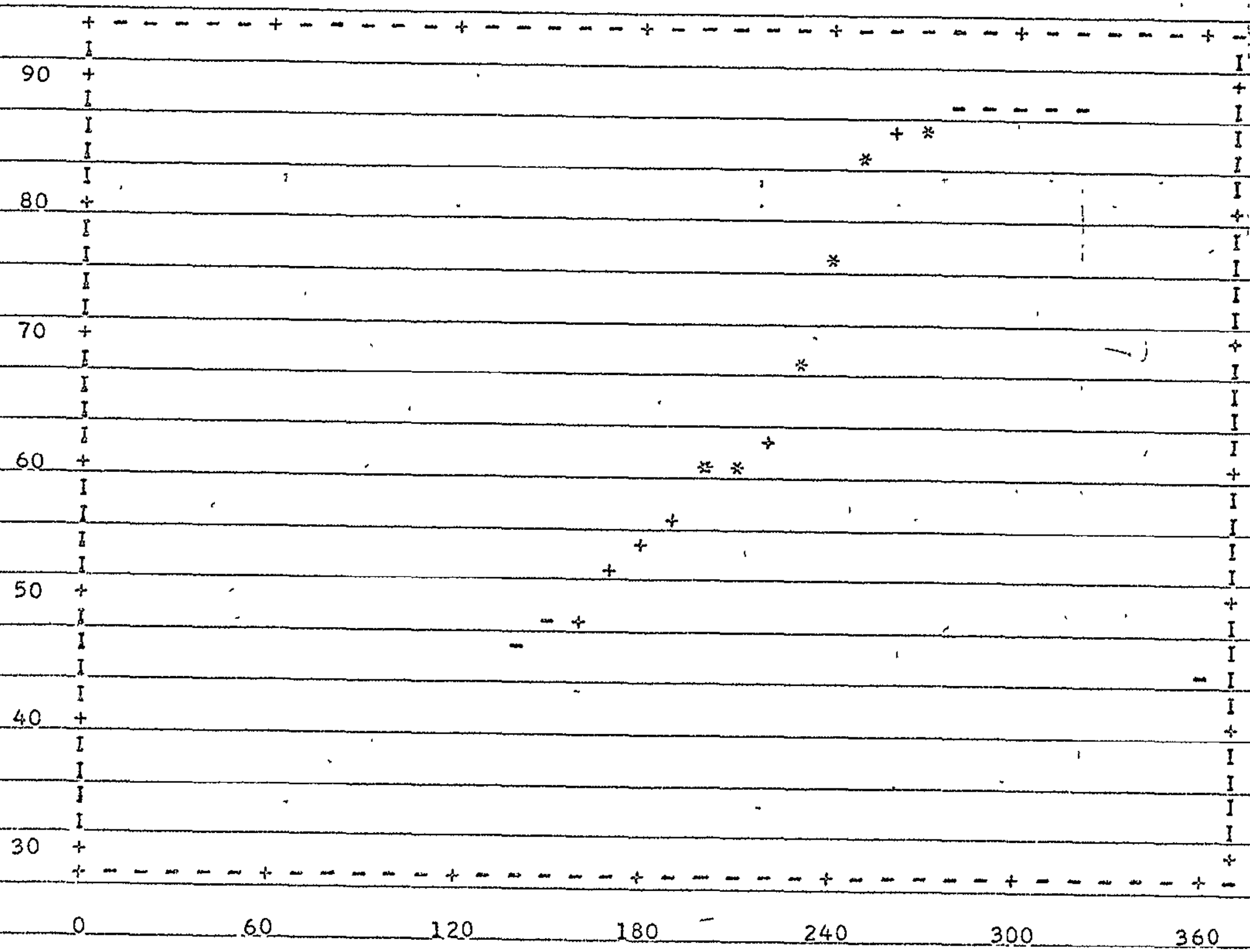
SOUTH POLE AT 150 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

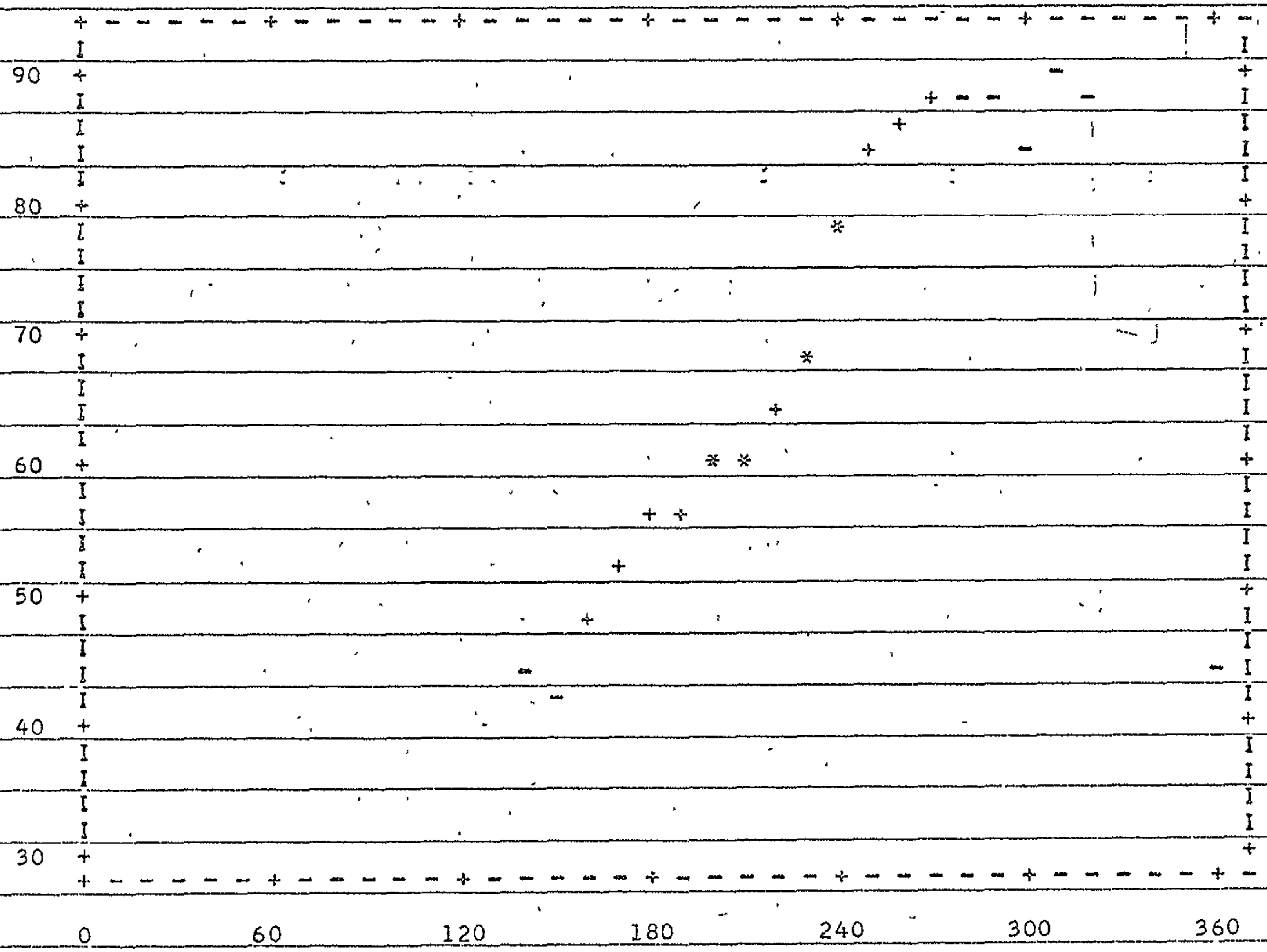
SOUTH POLE AT 160 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

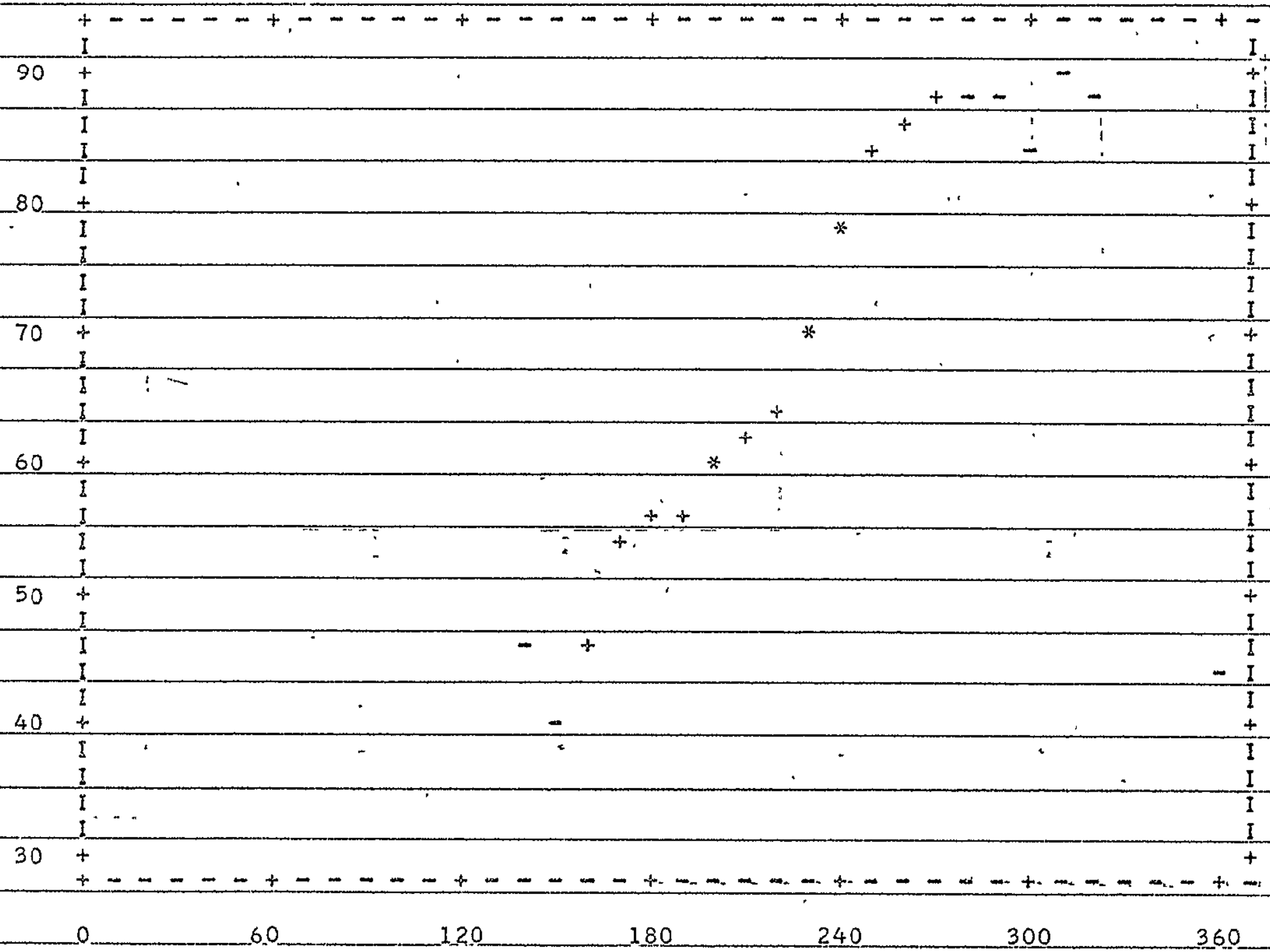
SOUTH POLE AT 170 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

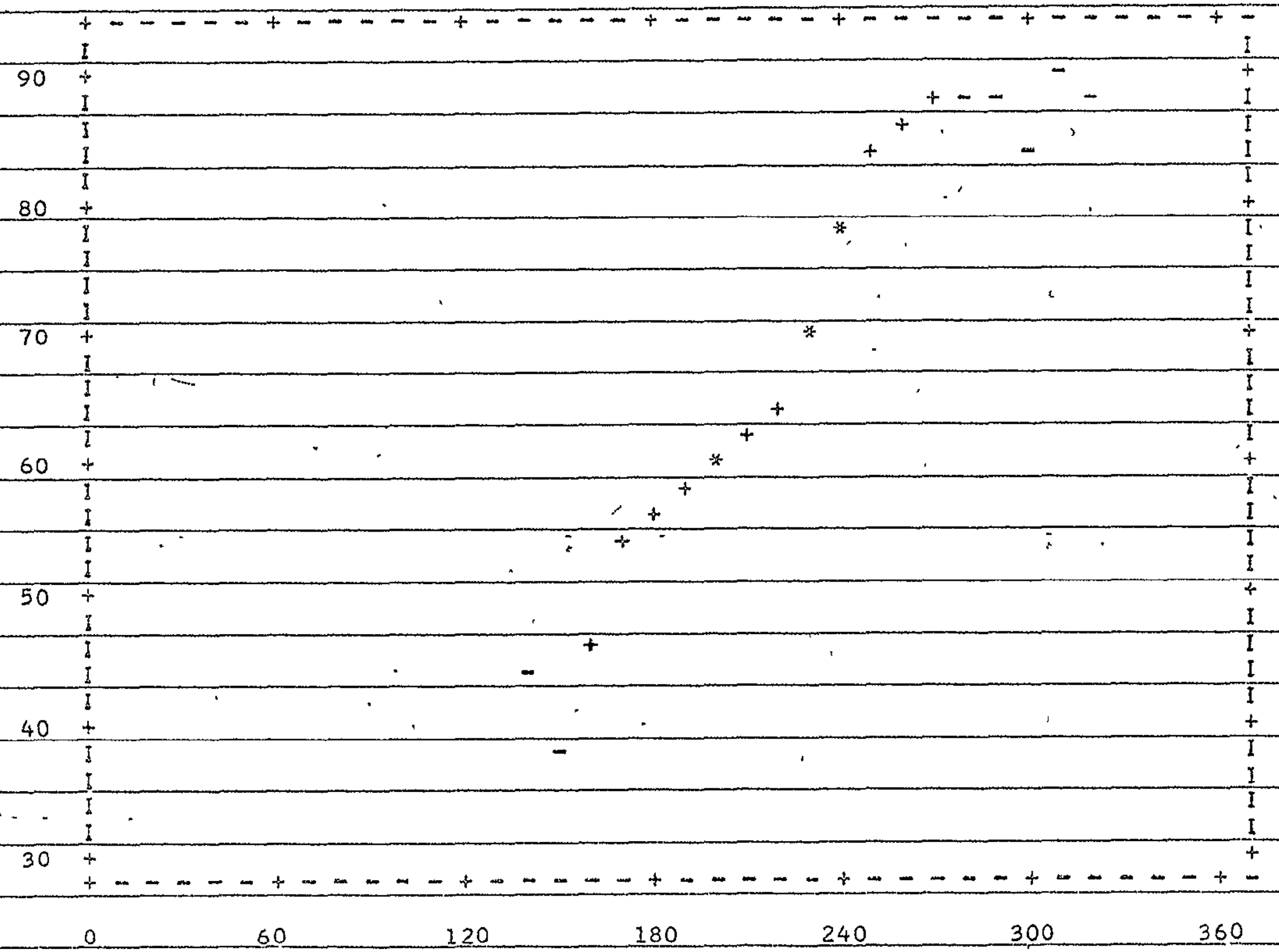
SOUTH POLE AT 180 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY   FLAGSTAFF, ARIZONA   NOVEMBER 27, 1968

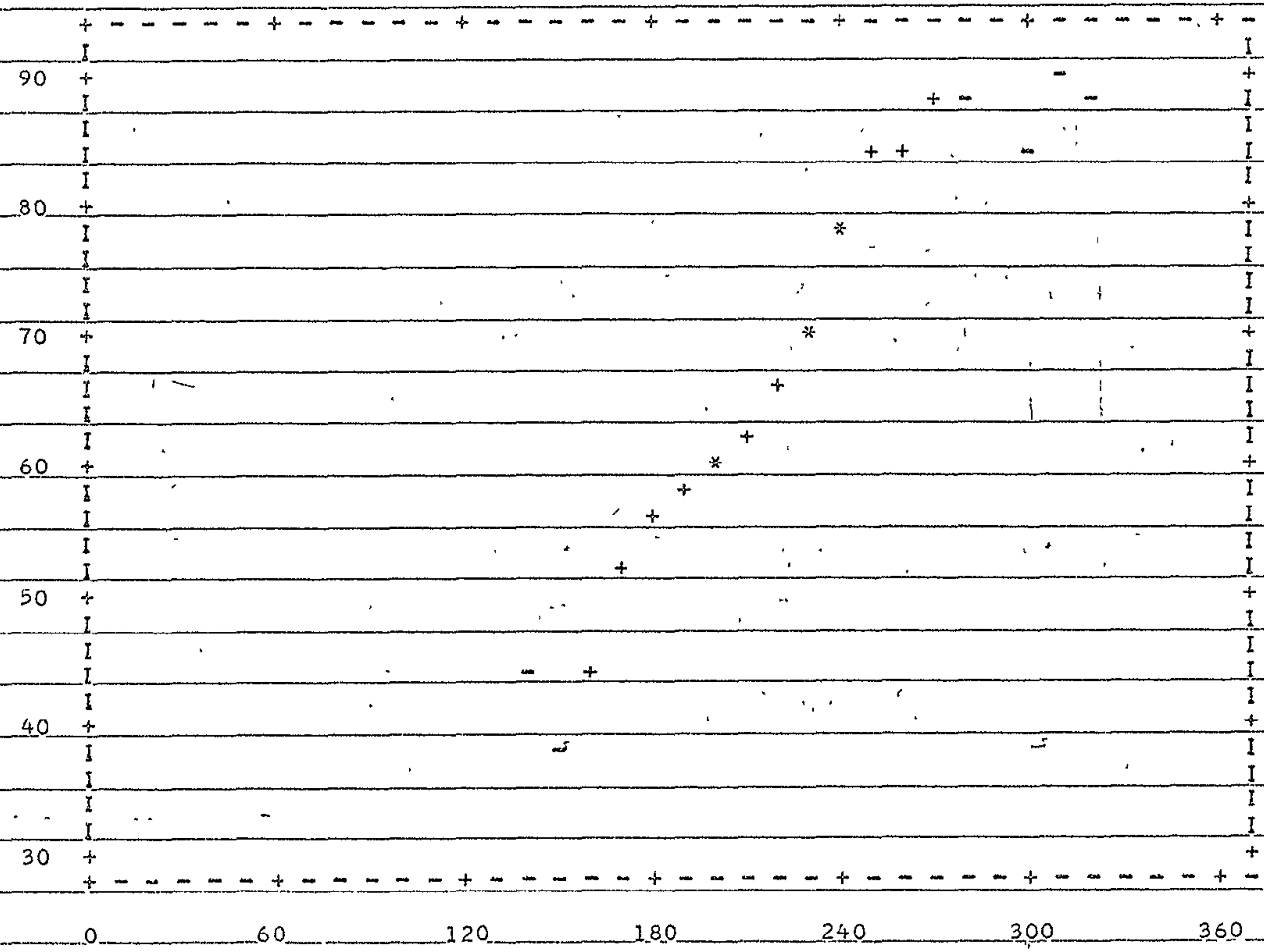
SOUTH POLE AT 190 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

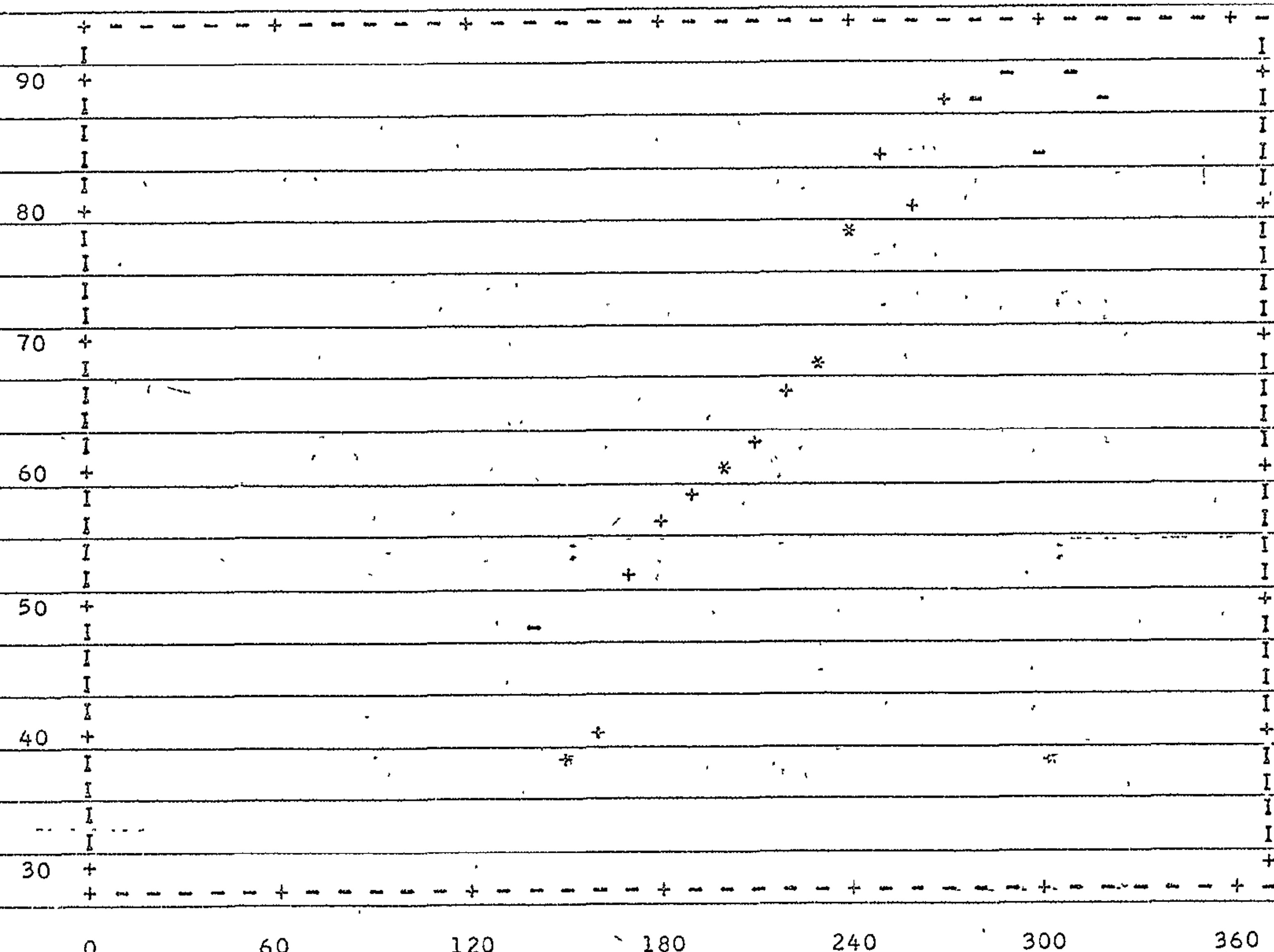
SOUTH POLE AT 200 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

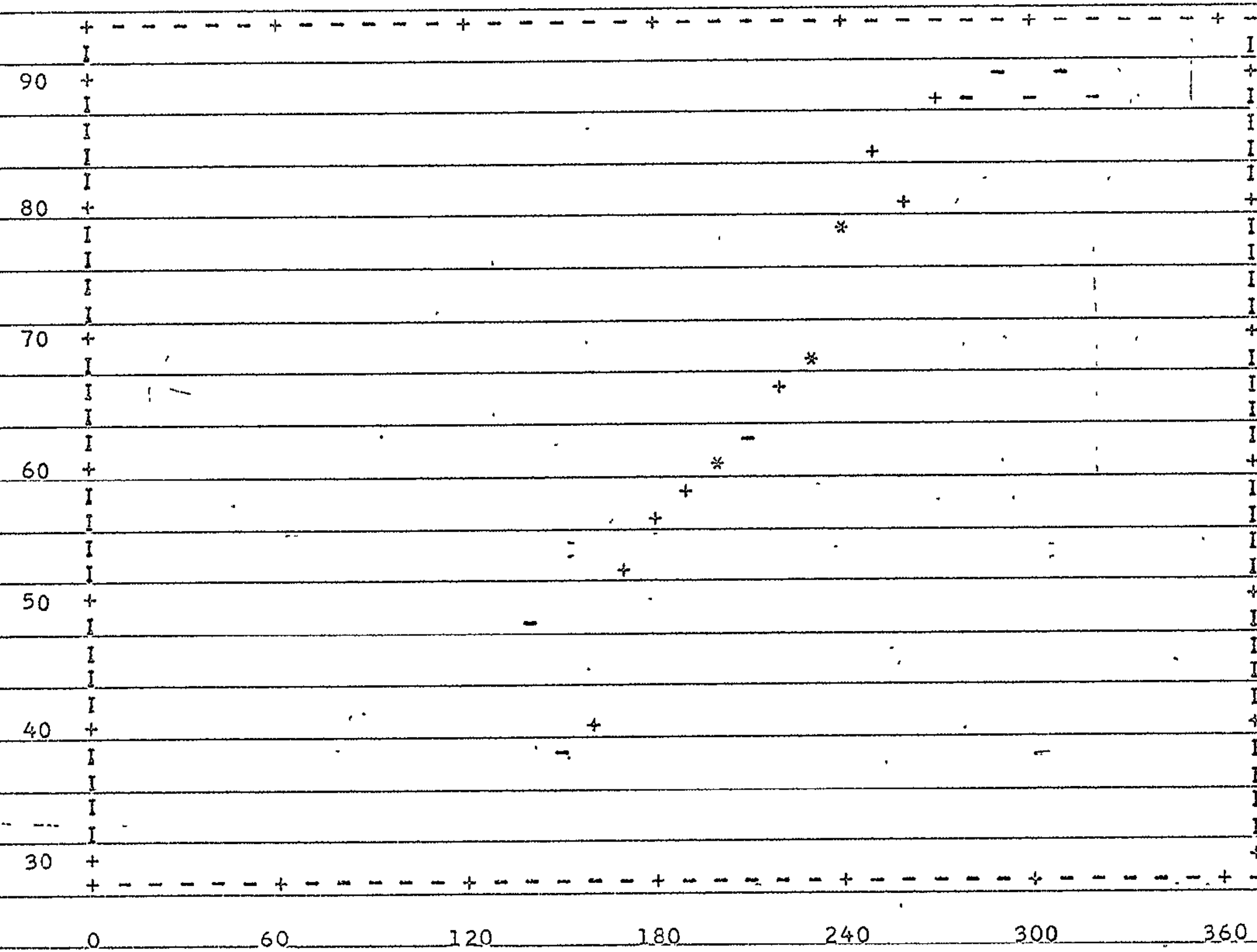
SOUTH POLE AT 210 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

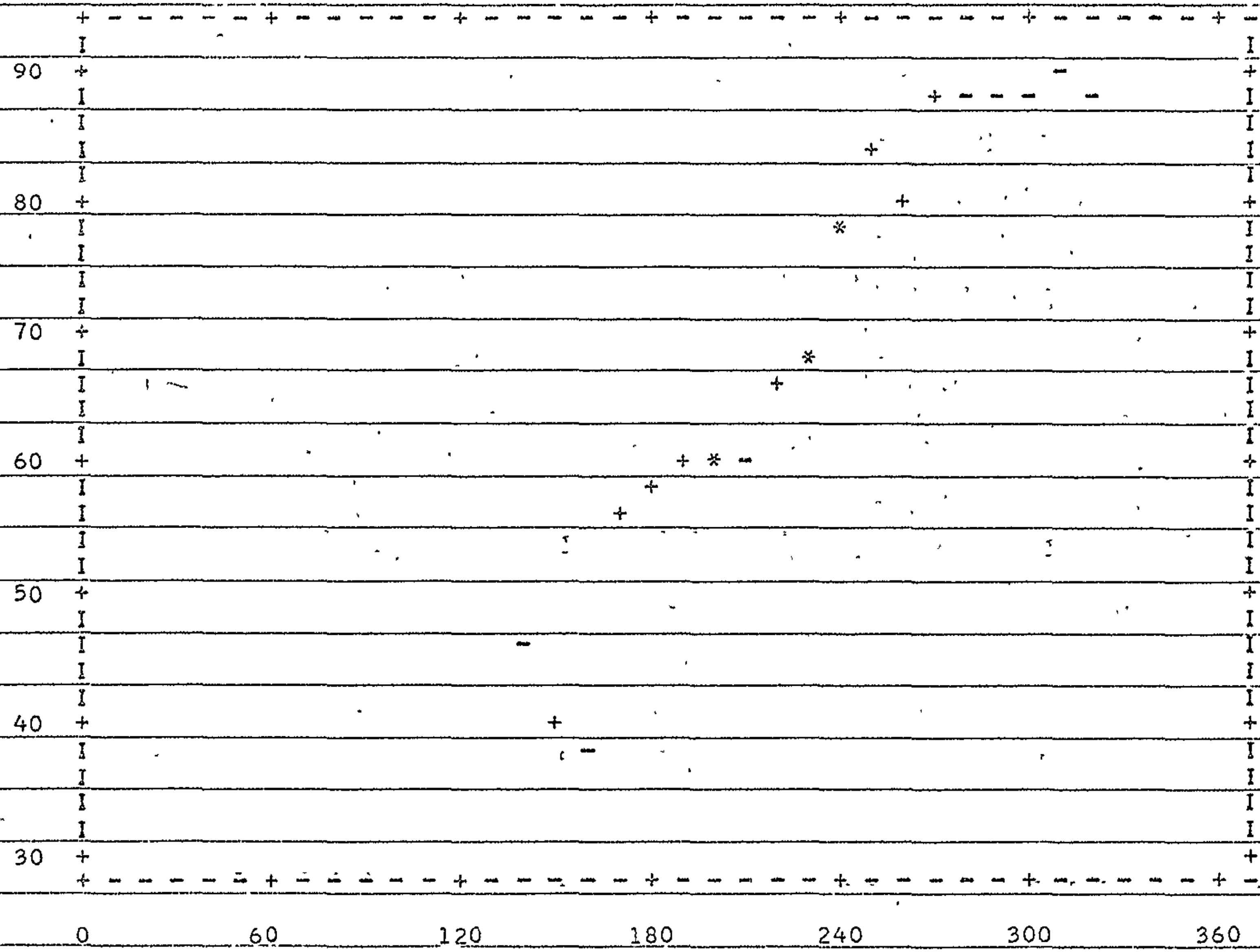
SOUTH POLE AT 220 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

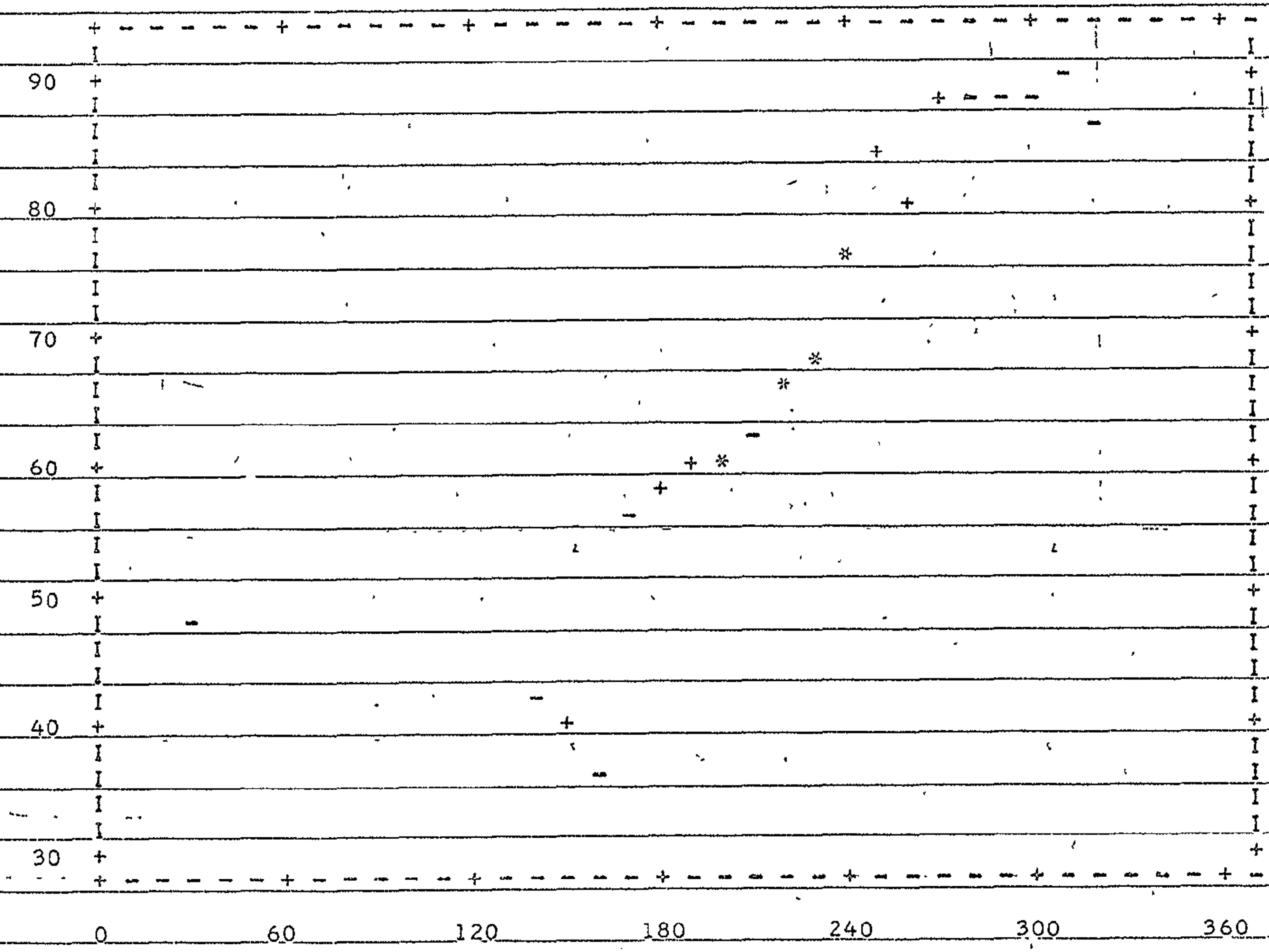
SOUTH POLE AT 230 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

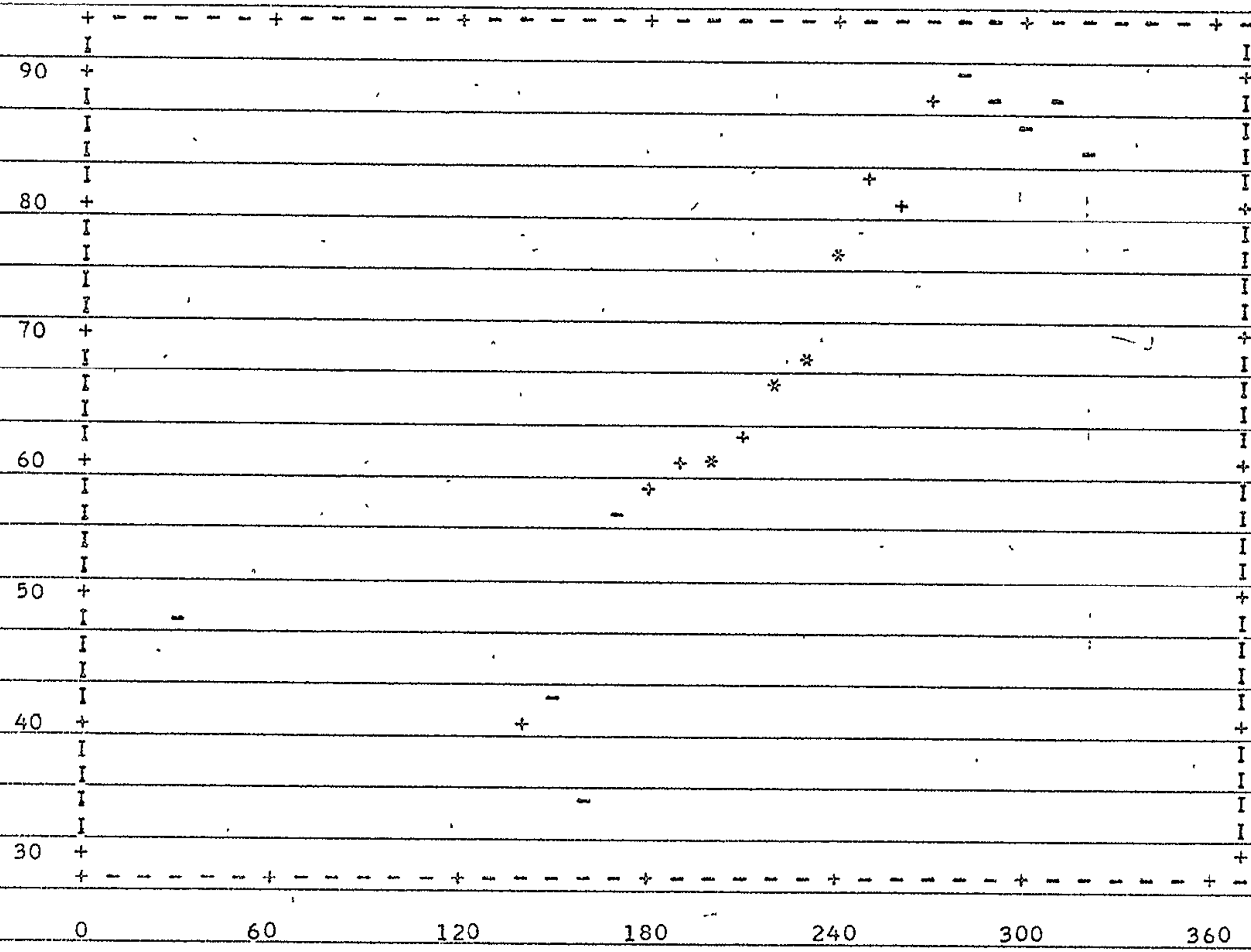
SOUTH POLE AT 240 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

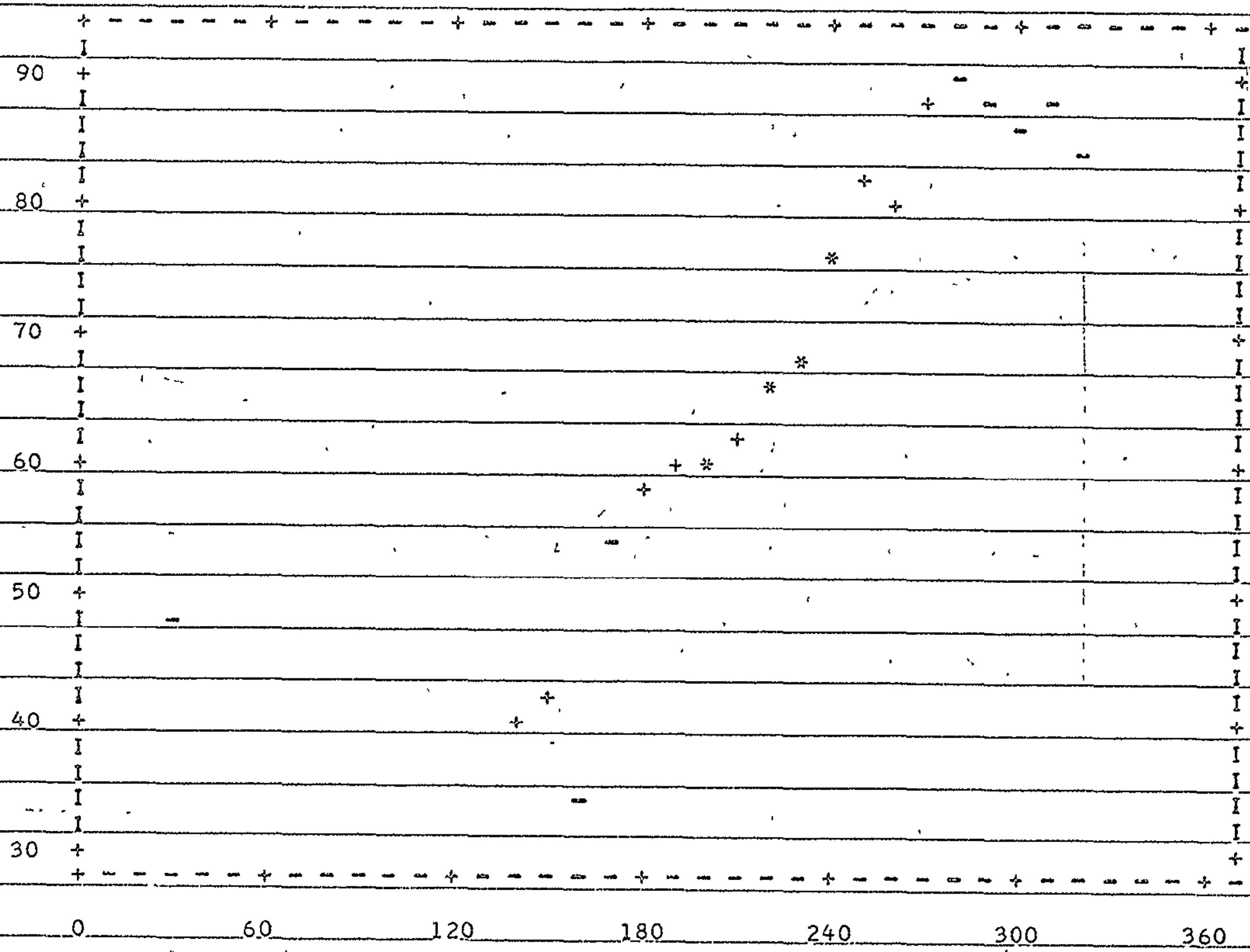
SOUTH POLE AT 250 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY   FLAGSTAFF, ARIZONA   NOVEMBER 27, 1968

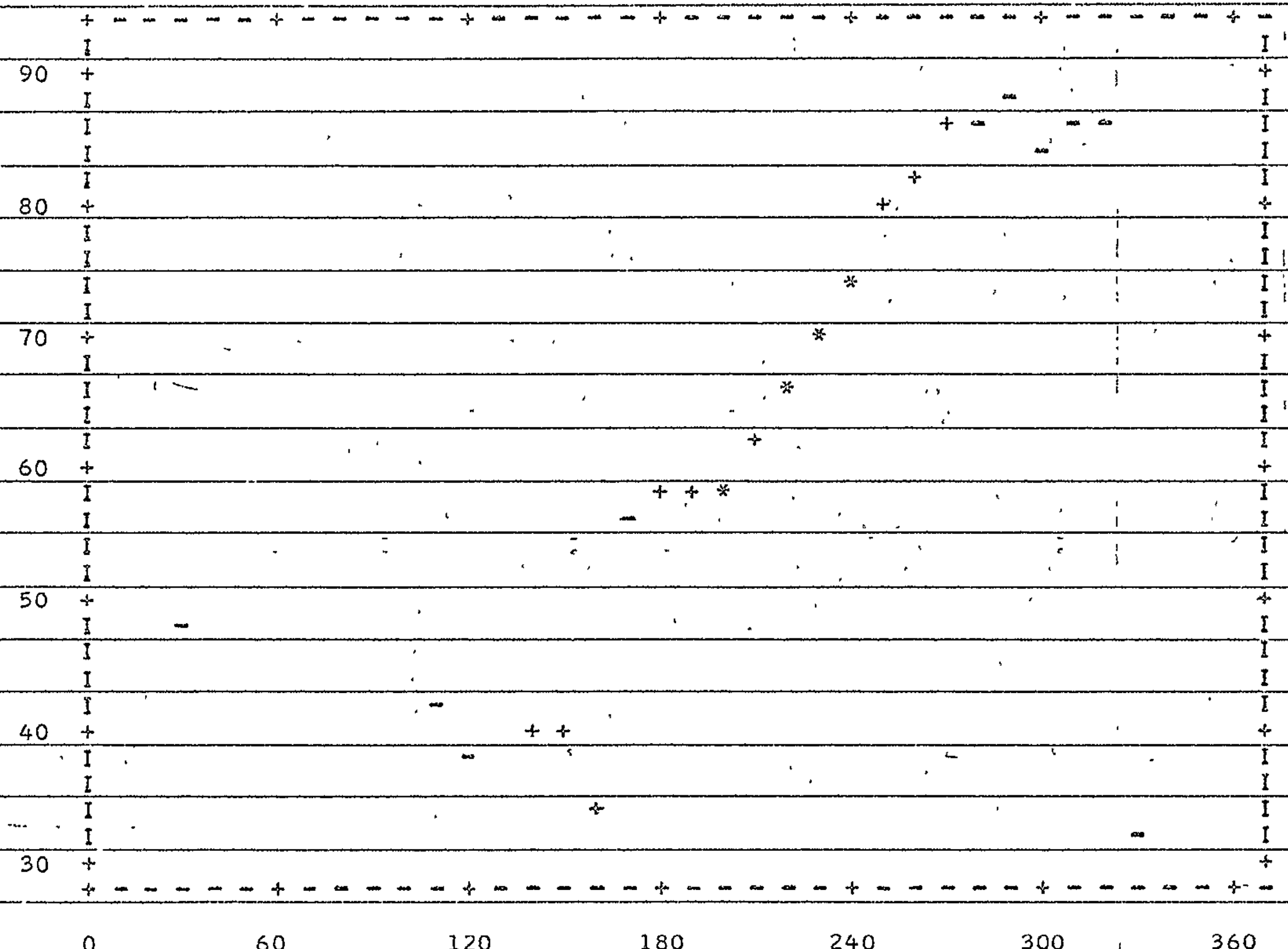
SOUTH POLE AT 260 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY   FLAGSTAFF, ARIZONA   NOVEMBER 27, 1968

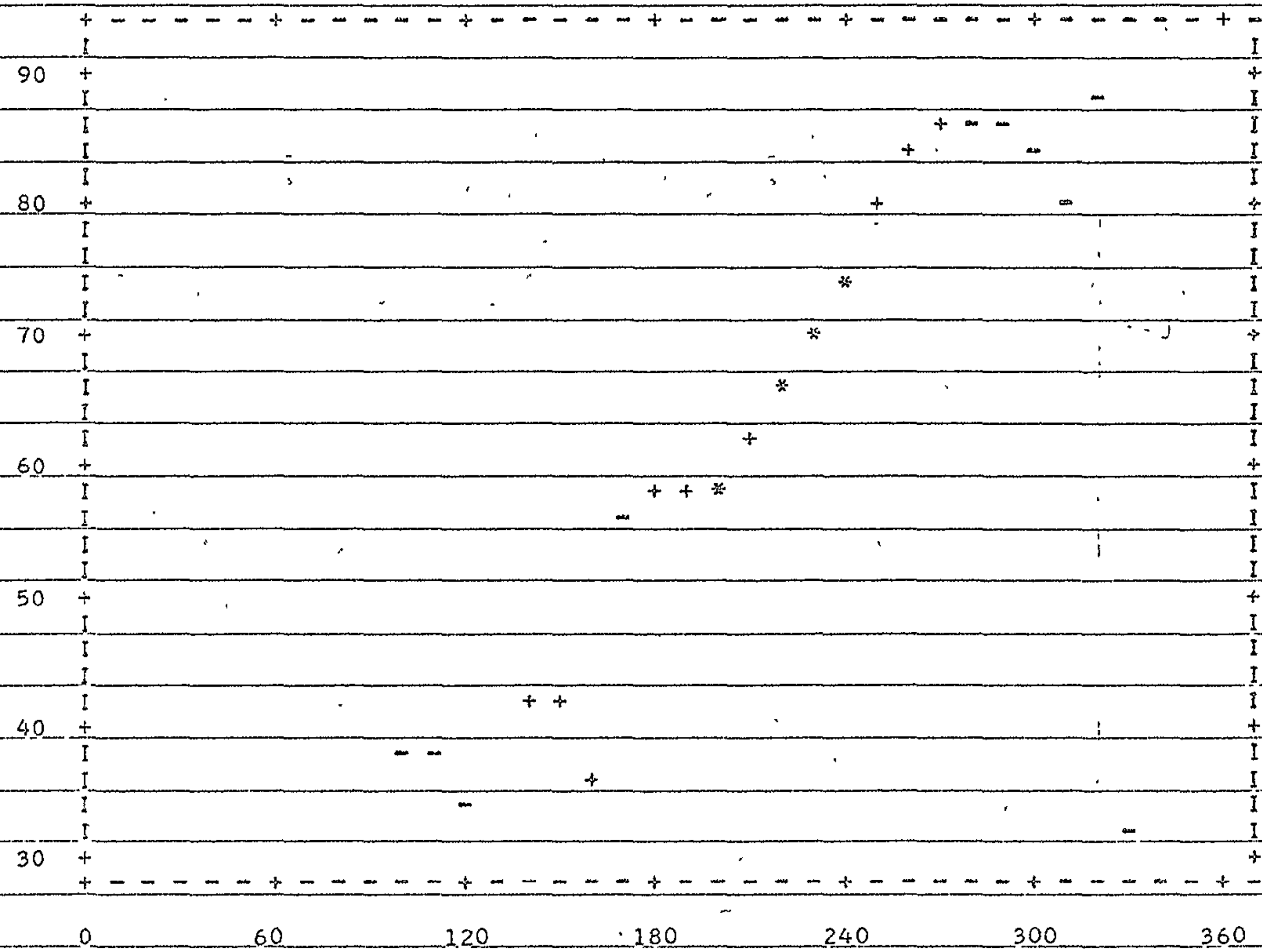
SOUTH POLE AT 270 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

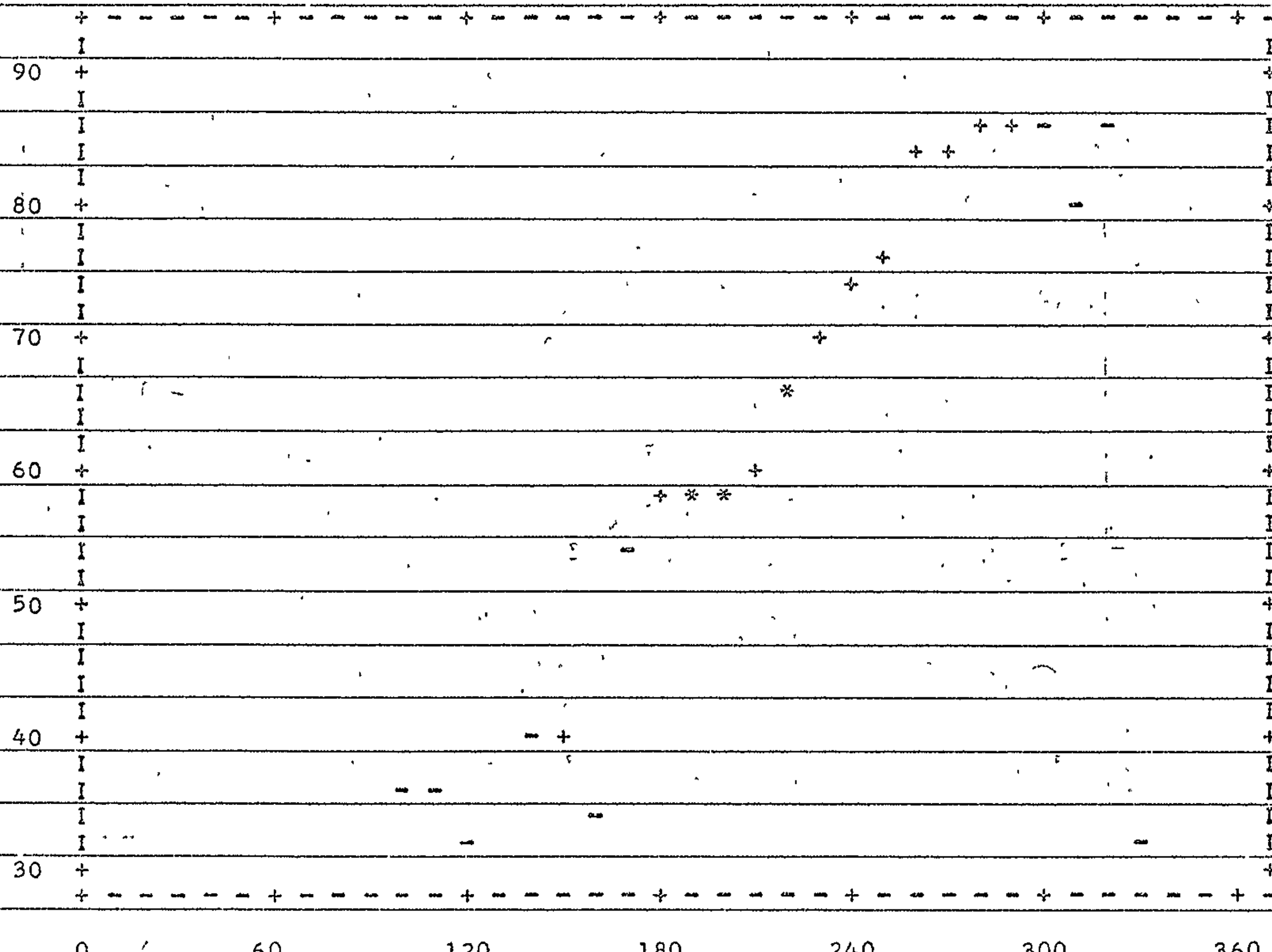
SOUTH POLE AT 280 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

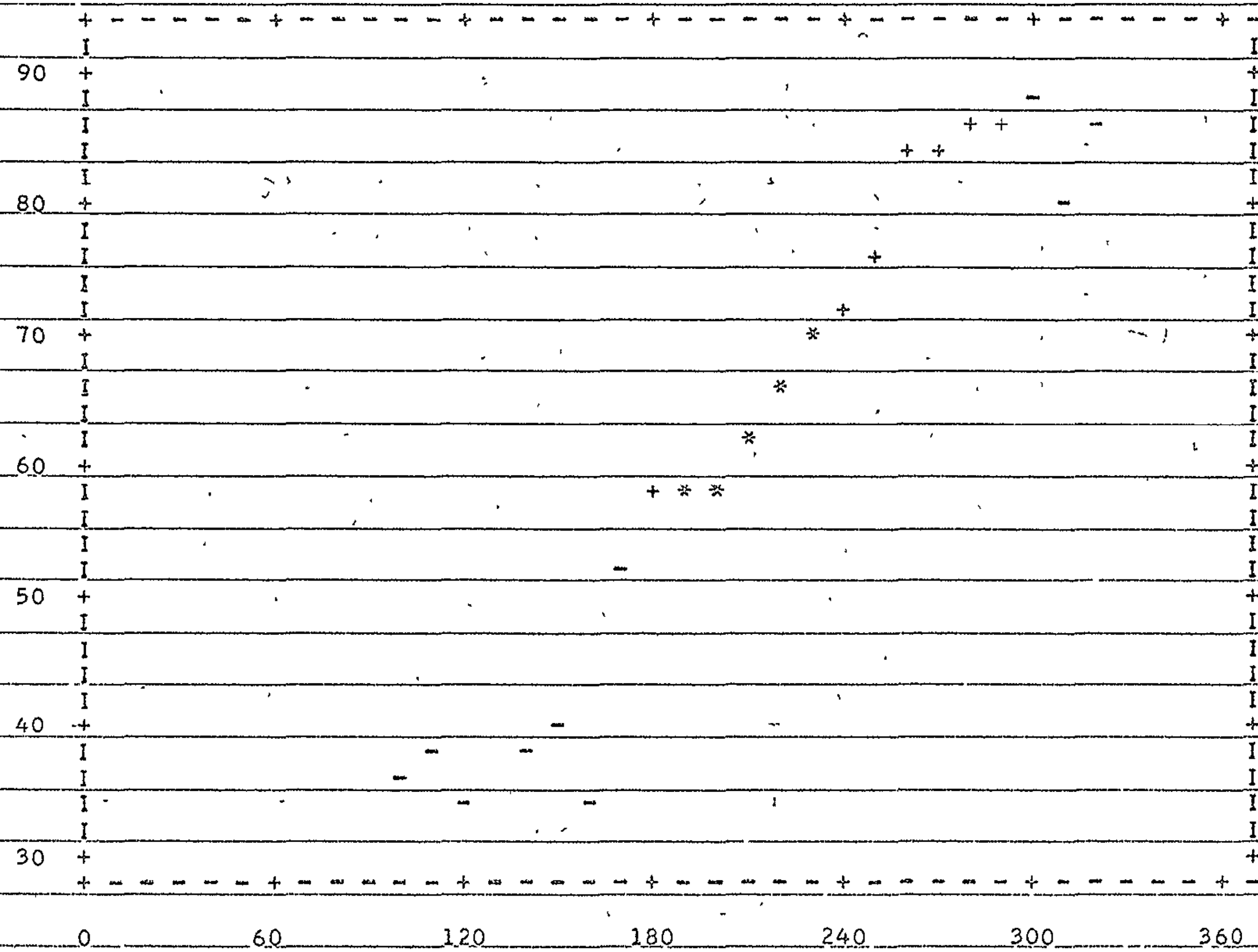
SOUTH POLE AT 290 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

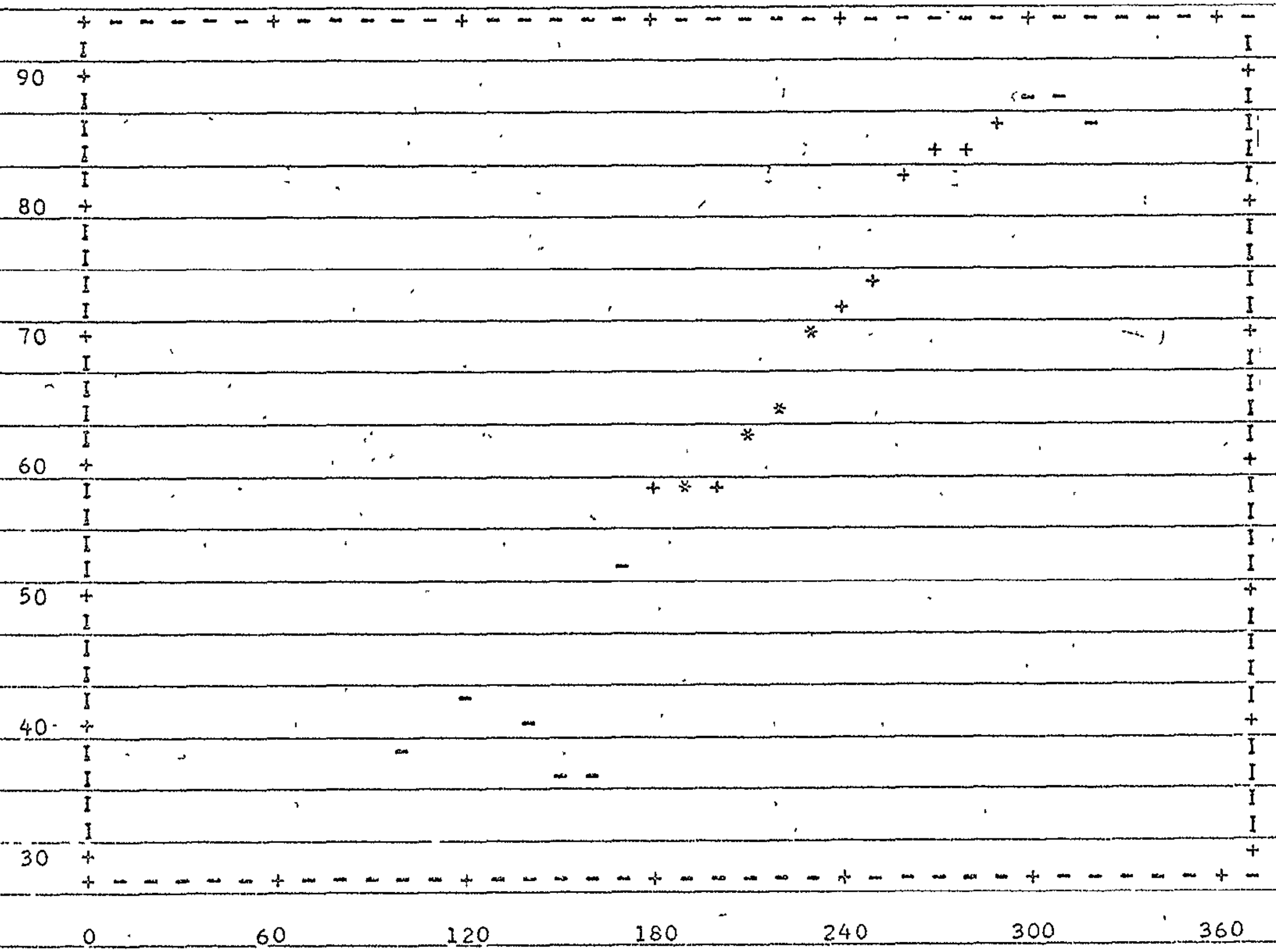
SOUTH POLE AT 300 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

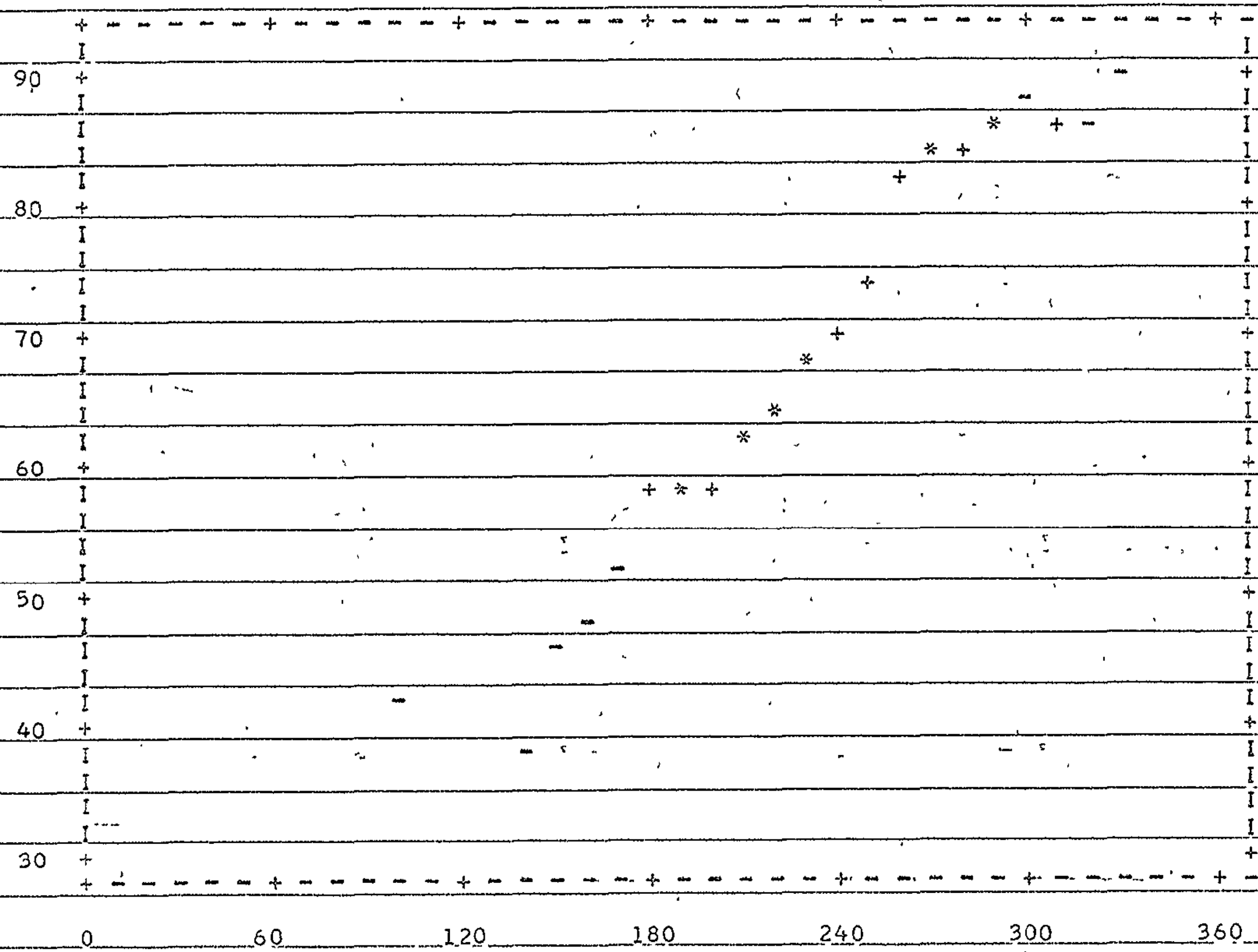
SOUTH POLE AT 310 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

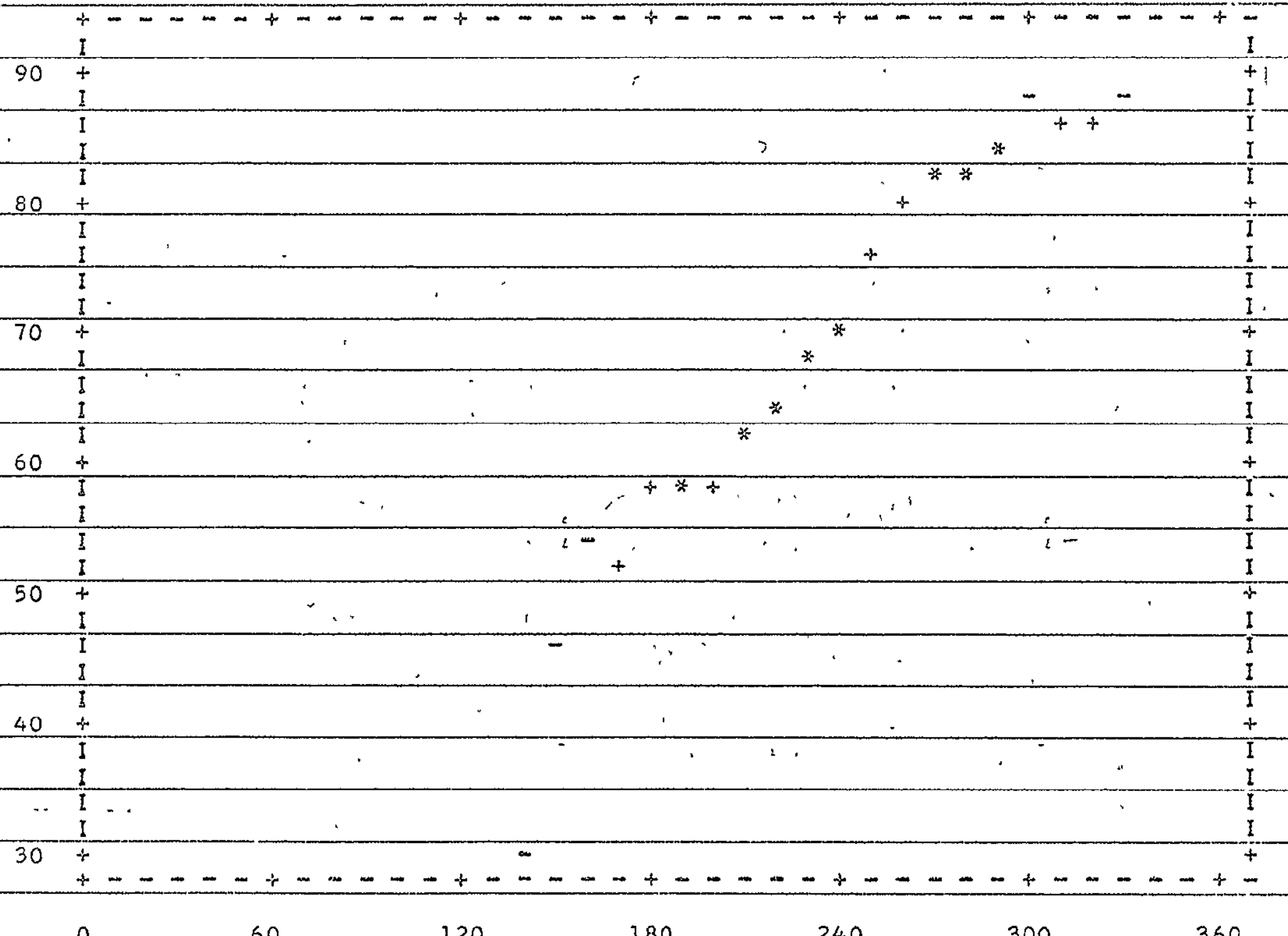
SOUTH POLE AT 320 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

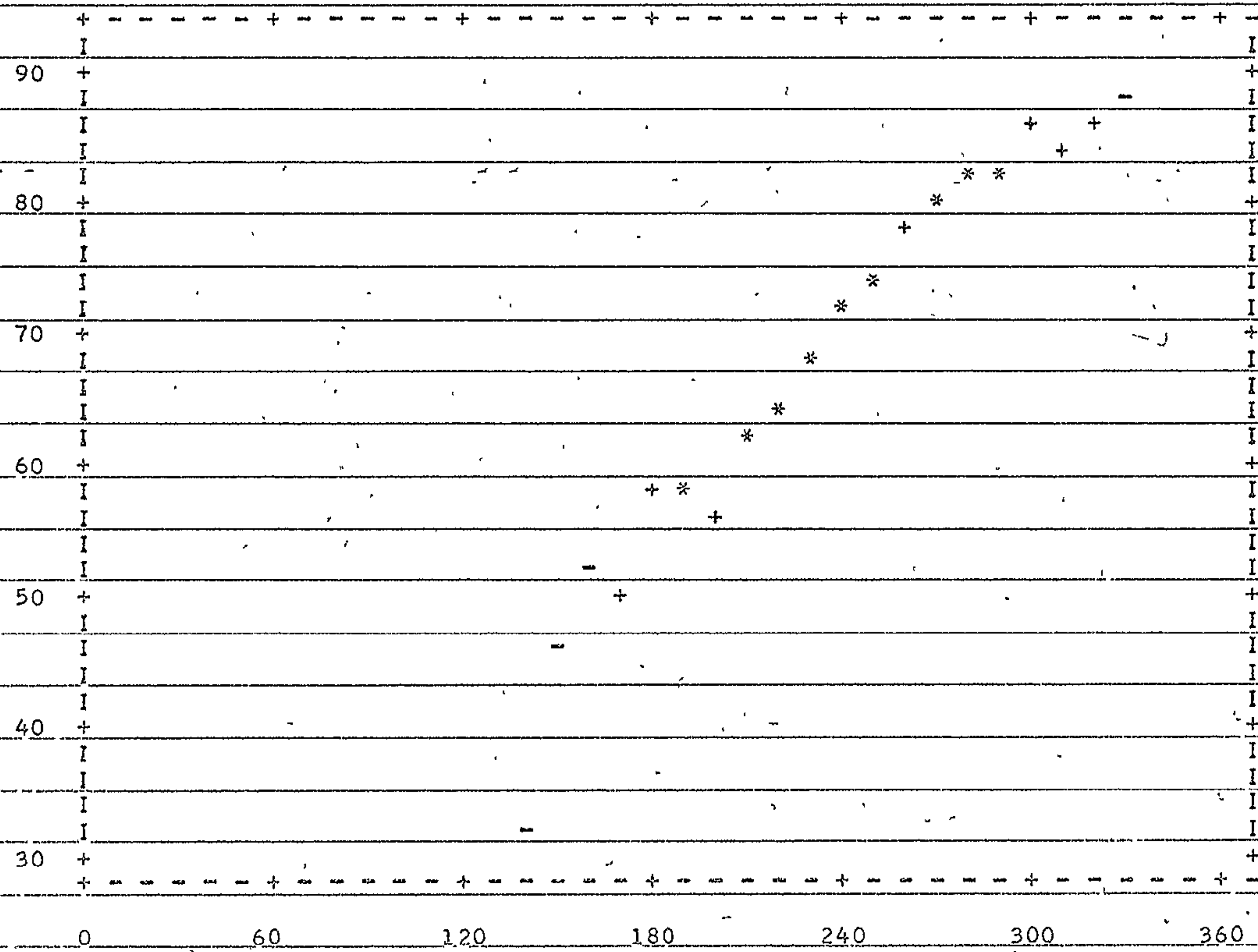
SOUTH POLE AT 330 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY   FLAGSTAFF, ARIZONA   NOVEMBER 27, 1968

SOUTH POLE AT 340 DEGREES AREOGRAPHIC LONGITUDE

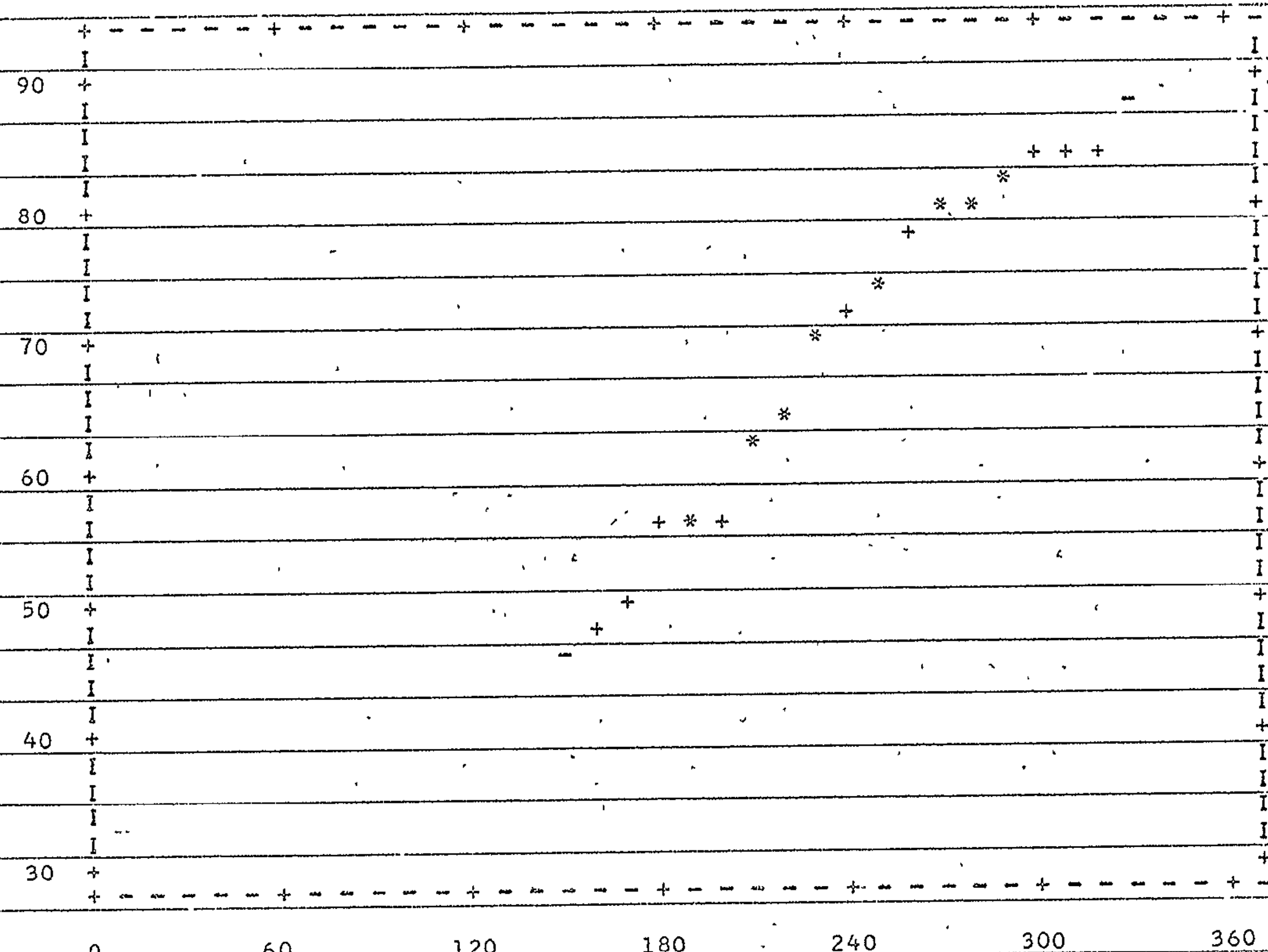


2

LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY   FLAGSTAFF, ARIZONA   NOVEMBER 27, 1968

SOUTH POLE AT 350 DEGREES AREOGRAPHIC LONGITUDE



LATITUDES OF MARS POLAR CAP VERSUS SEASON (ALS)

LOWELL OBSERVATORY FLAGSTAFF, ARIZONA NOVEMBER 27, 1968

SOUTH POLE AT 360 DEGREES AREOGRAPHIC LONGITUDE